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Virtual and Hands-on Laboratory Environments in the Science Classroom: The Effect of Prior Science Achievement

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Virtual and Hands-on Laboratory Environments in the Science Classroom:

The Effect of Prior Science Achievement

By

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Abstract

A study was conducted to investigate the extent to which previous science achievement affected student performance in traditional hands-on and virtual laboratory environments. A sample of 70 first-year college students was employed in a counterbalanced A-B-A-B experimental design. The study spanned four instructional weeks of laboratory experimentation alternating traditional and virtual learning environments. For each of the four labs, students were given a pre-test designed to measure content knowledge, administered the intervention of virtual labs, and this was followed by an identical post-test. Prior science achievement was assessed using a general chemistry assessment exam. T-tests revealed that student performance did not differ between the hands-on and virtual environments. Results of a MANOVA showed that virtual labs were more effective than hands-on labs for high-achieving students, whereas there was no difference for low-achieving students. Results of a second MANOVA revealed that high-achieving students outperformed low-achieving students on hands-on lab 3, virtual lab 3, and hands-on lab 4. Findings suggest that the use of virtual labs does not harm science achievement and may conserve resources, but may expand the gap between high- and low-achieving students in the science laboratory.

Keywords: virtual, hands-on, laboratory, virtual labs, VTL, HOL, blended laboratory, simulation, technology, science education, experimentation

Introduction

With the rapid advancements in technology, virtual lab experiences are being integrated into science classrooms and laboratory experiments. The ongoing discussion regarding student laboratory experiences is of value because previous research has shown that hands-on experiences in lab play an essential role in learning science (Hofstein & Lunetta, 2004). Researchers have discussed the presence of computer-simulated virtual labs as integrated members of post-secondary science education as early as the 1970s (Abdulwahed & Nagy, 2009; Campbell, 1985). Although reluctant to abandon the traditional hands-on lab experience, course instructors have slowly been integrating virtual labs (VTL) into the post-secondary science curriculum as either a supplement or replacement of hands-on experiments (Tatli & Ayas, 2013). Virtual labs are being introduced into the curriculum for two reasons. First, university administrators may seek to lower the cost of STEM content delivery and the higher cost of running the laboratories in the traditional fashion involving chemicals, instrumentation. Second, instructors may believe that virtual labs provide adequate or superior learning outcomes (Ma & Nickerson, 2006).

Traditional laboratory curriculum involves experiments dealing with hands-on investigations incorporating chemicals, glassware, Bunsen burners, and other physical laboratory equipment that aid in augmenting and demonstrating the scientific phenomena discussed in the lecture portion of the course. New nontraditional VTL environments include simulations that involve everything required for laboratory experiments; however, the entire experience is provided on computers, tablets, or other mobile devices. An example would be a virtual frog dissection provided by McGraw-Hill (2016), in which students are guided through the inner and outer anatomy of a frog and then are provided with post-lab quizzes and a formal lab report.

Newer virtual laboratory simulations involve software that places students in a simulated environment by including macro and micro dimensions through the use of images, interactive diagrams, and video, so that students can visualize abstract concepts (e.g., atoms moving at the molecular level; Chao, Chiu, DeJaegher, & Pan, 2016). These labs also provide students with synchronized sounds and virtual actions as they complete the virtual lab (Tatli & Ayas, 2013). In the digital age, students may feel more comfortable around computer simulations; however, many instructors are reluctant to give up traditional hands-on laboratory experiments due to the perceived value of the traditional hands-on lab setting (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014). Although research in this area is progressing, questions remain regarding the impact of virtual labs on performance in the science classroom.

In what follows, results of a study on virtual laboratory experiments will be explored with emphasis on the extent to which prior science achievement affects student learning of laboratory material. A review of research of the effectiveness of both the virtual and traditional hands-on laboratory experiences will be followed by a discussion of needed research in the extant literature. This discussion will be followed by a presentation of the research questions, hypotheses, and rationale for this study. After detailing the research methods, data collection, and analytic procedures, the findings of this study will be presented with educational implications that will add to the growing body of research on the use of virtual laboratory experiments.

Review of Related Literature

Effectiveness of Virtual Labs (VTLs)

Ma and Nickerson (2006) performed a literature review on virtual labs, particularly simulations, hands-on labs, and a blended learning environment that combines virtual and hands-on elements. The analysis of 60 papers published up until 2005 demonstrated that the area of VTL studies had a wide disciplinary spectrum, although a majority of the articles were focused on engineering education. Over 53% of the 60 studies focused on outcomes related to content knowledge, with a large amount (40.71%) of the studies using traditional multiple-choice tests to assess the effectiveness of the treatments. The least assessed learning objective was science inquiry skills (4.7%). The authors conclude that there is not enough empirical evidence supporting the full implementation, or removal completely, of virtual laboratory experiments. The following literature review extends past the literature search conducted in 2006, with the exception of a few for historical context, and focuses on various studies measuring the overall effectiveness of virtual labs (simulations only) compared to hands-on experimentation, as well as different implementations of the blended learning environment (both hands-on and virtual lab components), which Ma and Nickerson did not review.

Unlike traditional lab experiments, virtual lab simulations use an array of media that might help span the gap between different student learning styles and teaching styles.
In one of the earliest studies on the effectiveness of virtual labs, Gokhale (1996) conducted a quasi-experimental study that involved 32 undergraduate physics students who were separated into two lab groups working on circuits and amplifiers. The experimental group used computer simulated virtual labs, while the control group conducted traditional hands-on lab activities. Both groups experienced a pre-lab, lecture session, and post-lab experiment on the same concepts. The computer-based virtual lab provided instant and reliable feedback to the participants and gave the students an opportunity to attempt different options of connecting electric circuits as well as evaluate different solutions for accuracy very quickly. An analysis of covariance (ANCOVA) showed a significant difference favoring the virtual lab group of participants on a problem-

oriented test, but showed no statistical significance between the virtual and hands-on lab groups on a drill-and-practice test. Gokhale (1996) asserts that the virtual labs can be utilized as an alternative to hands-on labs and may help students with their higher order thinking skills. The traditional hands-on lab provided an environment where students had to account for both physical and mental activity; whereas, virtual labs provide an environment where students only had to account for mental activity which in turn may reduce the cognitive load for the students. This study was conducted within a time period during which students were not completely saturated with technology and mobile devices. This lack of proficiency and access to computer use may have contributed to the difference favoring the virtual lab group. This study employed a computer simulation that formed the basis for future laboratory simulations in science courses.

A more recent study looked at the effectiveness of virtual labs by substituting the actual physical lab equipment with a computer simulation. Finkelstein et al. (2005) examined a total of 107 participants using either real equipment or a computer simulation that modeled electron flow. The authors noted that the results on the final examination demonstrated that students who were in the virtual lab environment had a better mastery of circuits. The measures in this study included laboratory write-ups and performance on a final exam. The authors reported a lack of statistically significant differences at the $p < .01$ level (two-tailed t-test) between groups on non-circuit questions, but significant differences on circuit questions. When asked to explain the content of the laboratory, students in the virtual lab were more thorough in their descriptions of the phenomena. The more thorough descriptions may be due to the virtual simulations providing direct perceptual access to the concept of current flow and electrons moving through a current.

In a similar study with opposing results, Hawkins (2013) investigated 169 students taking a general chemistry course. The participants were broken up into lab sections and each lab section completed either the virtual lab or the hands-on lab. Virtual lab sections met in the regular lab and then moved to the computer lab to complete the virtual simulations. A t-test showed that there was no significant overall difference between the two lab teaching methods when comparing pre- and post-test data, which focused a conceptual understanding of the topic. There was a significant difference favoring the hands-on lab group on one item of the post-test that included the physical placement of a salt bridge (which maintains electrical neutrality within an internal circuit). The hands-on group had to place the salt bridge in the correct spot in order to see any results, as the salt bridge was critical for the lab to produce accurate data. The virtual lab students may have left the salt bridge out more than the hands-on lab students because the virtual experience did not require students to place the salt bridge in the correct spot when setting up the lab experiment. Hawkins (2013) raised the major concern here that virtual labs do a poor job of teaching laboratory techniques, such as properly setting up a salt bridge for electrochemistry.

Similar to the findings of Hawkins (2013), virtual lab were equally as effective as traditional hands-on labs (Zacharia & Constantinou, 2008). Unlike Hawkins (2013), Zacharia and Constantinou controlled for the method of instruction and the resources available to the students in both the virtual and hands-on environments. The study involved 68 undergraduate students taking an introductory physics course. A one-way analysis of covariance (ANCOVA) showed no significant differences between the hands-on and virtual manipulative lab groups, which suggested that the virtual manipulative groups were just as effective in promoting student understanding of temperature. A t-test showed significant differences between scores on the pre- and post-test with both the control and experimental groups, which indicated that both groups did gain conceptual knowledge about the topic.

In another more recent study that produced similar results, a quasi-experimental research design was utilized to test the effectiveness of virtual labs compared to traditional hands-on lab physics experiments on accelerated and simple harmonic motion (Darrah, Humbert, Finstein, Simon, & Hopkins, 2014). Two different sets of participants were used in this study, as it was implemented at both Auburn University and Penn State University. The first set of participants (n = 68) from Auburn were already assigned into four lab classes and students in each lab class were asked if they would be willing to participate in the study. The second set of participants (n = 156) was also already assigned into four separate lab classes. The authors ran multiple statistical procedures on the groups of students including t-tests, ANCOVA, one-way ANOVA, and MANOVA. At both universities, the authors found no statistically significant differences between students performing virtual labs and students performing hands-on labs. Darrah et al. reported that virtual labs were as effective as hands-on physics labs and concluded that virtual labs can be utilized as an alternative to traditional hands-on lab experiments.

In the several studies that found virtual labs to be more effective (Finkelstein et al., 2005; Gokhale, 1996), general trends emerged. Outcomes of these studies indicated that students in the virtual lab were more thorough in their descriptions of the phenomenon, and virtual labs have led to more activities that facilitated higher order thinking, because it allowed more attention to be paid to process rather than lab techniques. In contrast to these results, in studies that found no difference in effectiveness between virtual and hands-on labs (Darrah et al., 2014; Hawkins, 2013; Tatli & Ayas, 2012; Tatli & Ayas, 2013; Zacharia & Constantinou, 2008), researchers have suggested that virtual labs might lead to students not being comfortable with or efficient at using physical laboratory equipment. Although divided among overall findings, there seems to be a general consensus among researchers that the effectiveness of virtual labs suggests that they should be utilized as a supplement, and not a replacement for traditional hands-on labs (Darrah et al., 2014; Ma & Nickerson, 2006; Tatli & Ayas, 2013).

Chronological Order of Hands-on and Virtual Labs (VTLs)

Numerous authors have noted the possible benefits of combining virtual and hands-on learning activities (Chao, Chiu, DeJaegher, & Pan, 2016; Olympiou & Zacharia 2012; USDOE, 2010). Accordingly, studies have also been performed to determine the order in which virtual and hands-on learning environments are presented. One such study was conducted by Erdosne, Toth, Morrow, and Ludvico (2009), who explored ordinal effects in an introductory biology course. A mixed method design study was employed that consisted of 42 students in two different laboratory sections. One group of students was first provided with a virtual lab experience, which was followed by a hands-on learning experience. The second group started their learning experience with the hands-on lab followed by the use of the virtual lab experience. The pre- and post-tests yielded quantitative data on students' facility with experimental design and conceptual knowledge. A reflective questionnaire yielded qualitative data about participants' learning and opinions regarding the benefits of the different laboratory environments. An analysis of covariance (ANCOVA) documented no significant effect of presentation order, but demonstrated a significant effect when students encountered both virtual and hands-on components simultaneously. The qualitative results showed a strong preference by students to have the virtual work preceding the hands-on laboratory. The same preference was also seen in a previous study in which students preferred to complete the virtual component first, as they found it beneficial to preview the material they would then see in the hands-on portion of the experiment (Swan & O'Donnell, 2009). Erdosne, Toth, Morrow, and Ludvico (2009) found that students reported difficulties with laboratory equipment in the traditional hands-on lab; however, the students noted the benefits of traditional lab environments. For example, the students recognized the role of error in real-world collection of data, as opposed to simulated scenarios of virtual labs, which do not account for any environmental factors that may lead to error (Erdosne Toth, Morrow, & Ludvico, 2009).

In a later study, Toth, Ludvico, and Morrow (2014) explored both virtual and hands-on learning environments and studied the benefits of using virtual labs to ground students' knowledge construction before more complex hands-on labs. The study examined 32 first-year college students in an inquiry-based, introductory college biology course at a private university. For the study, half of the students completed the traditional hands-on learning environment, and then the virtual learning environment. The other groups performed the experiment in the opposite order. The virtual lab was found to be effective (ANCOVA) for aiding in student learning of basic concepts and skills during the first part of the lab experiment with a large effect size (Cohen's $\eta = 0.67$). Students were then successfully able to apply what was learned during the virtual lab when transitioning to hands-on lab experimentation. Toth, Ludvico, and Morrow (2014) went on to discuss the lack of success when the hands-on learning came first, followed by the virtual learning experience. These students were less successful in learning the basic skills and concepts needed for gel electrophoresis. Though the group that engaged in the hands-on learning first did learn the correct biology concepts, the authors report that learning appeared to have been less deep and less purposeful than the group that first encountered the virtual lab.

Although few studies were performed that primarily looked at the chronological order in which virtual and hands-on learning activities were presented (Chao, Chiu, DeJaegher, & Pan, 2016; Olympiou & Zacharia 2012; USDOE, 2010); overall, it appears that students had a preference for introducing the virtual components of the lab prior to the hands-on elements of the lab as a way to preview the physics material. The consensus among researchers suggested that presenting the virtual lab first might be a way to introduce laboratory equipment to the students, and model the correct way in which to use the equipment physically (Hawkins, 2013; Toth, Ludvico, & Morrow, 2014). This can create an environment in which students can feel more comfortable and safe with physical lab equipment and instrumentation. The virtual lab may also introduce the theoretical way in which the lab is "supposed" to go, making it easier for students to identify errors associated with real hands-on experimentation (Hawkins, 2013).

Combining Hands-on and Virtual Labs in a Blended Learning Science Laboratory

Blended learning science laboratories are learning environments in which hands-on and virtual procedures are introduced to students simultaneously. In an early study, this blended learning classroom was compared with hands-on or computer modeling labs alone (Liu, 2006). A quasi-experimental study involving 33 chemistry students was performed in which students were divided into two separate groups. Each group, once divided by the instructor, completed a particular sequence of computer modeling and hands-on laboratories. Both groups then completed a blended lab experiment. As a measurement tool, one pre-test and two post-tests of conceptual understanding of gas laws were completed. In the pre- and post-tests, both multiple choice and open-ended questions were presented to the students in order to account for the internal validity threat of pre-test sensitization on the post-test answers. Liu (2006) reported that given the small sample sizes and the fact that measurement on dependent variables was on an ordinal scale, non-parametric inferential statistics were used. A Mann–Whitney test was used to compare the two groups, and the Friedman test was used to compare results between repeated measures. A combination of hands-on and virtual components in a lab were found to be more effective than either a virtual simulation or a hands-on activity alone in promoting conceptual understanding of gas laws, according to Wilcoxon's signed ranks test. According to a Friedman's one-way analysis of ranks on repeated measures, there was a statistically significant difference in the mean ranks among pre- and post-test questions related to the relationship between temperature and pressure of gases.

In a recent study, Chao, Chiu, DeJaegher, and Pan (2016) noted that combining physical and virtual labs could provide students with the benefits of both learning environments. The authors presented a laboratory experience that simultaneously provided connected physical and virtual experiences for the students in an experiment on gas behavior. They argued that this arrangement had the potential to promote connections between the two different learning environments. A quasi-experimental design ($n = 30$) was utilized to compare traditional instruction with a virtual and hands-on hybrid sensor-based lab on the gas laws and kinetic molecular theory. Paired sample t-tests and an analysis of covariance (ANCOVA) were utilized to compare pre- and post-test data. Compared to traditional instruction with sensor-based labs, the hands-on/virtual hybrid lab did not show significant differences in test results, suggesting a lack of an overall advantage of using the blended method. Regardless, the paired sample t-test indicated that the group of students experiencing the hands-on/virtual hybrid lab significantly improved their overall test performance with a large effect size. Chao, Chiu, DeJaegher and Pan's (2016) blended method presented a tangible macroscopic event and paired it with the underlying molecular behavior simultaneously, which helped with certain abstract concepts; however, the small sample size of this study limits the usefulness of the results, as it may have affected statistical significance.

In 2010, the United States Department of Education (USDOE) conducted a meta-analysis of hands-on, virtual, and blended learning environments. The majority of the 10 studies reviewed that directly compared purely online and blended learning lab environments found no statistically significant differences in student learning. Out of these studies, seven studies found no significant difference between the two, two found statistically significant advantages for purely online instruction, and one found an advantage for blended instruction. The meta-analysis further showed that, on average, virtual simulation labs were slightly more effective in improving student learning outcomes than traditional hands-on lab experiments during random-assignment experimental design studies and studies with the largest sample sizes. As seen with previous studies, laboratory environments that combined virtual and hands-on learning parts had a large advantage compared to traditional hands-on learning experiments. Also, the meta-analysis presented larger effect sizes for studies in which virtual labs were collaborative (students working together) or instructor-directed, rather than those where students worked independently to complete the laboratory experiments.

Overall, the blended laboratory method appears to be the direction in which much current research is heading, although only two positive results were found to promote this learning environment (Liu, 2006; USDOE, 2010). Researchers have suggested the virtual lab should be utilized as a supplement to the traditional hands-on learning environment (Hawkins, 2013; Olympiou & Zacharia 2012; Trundle & Bell 2010), as students have an overall positive view of the virtual lab experiments. At this point, however, results indicate that more research needs to be conducted on the blended learning environment, in which virtual and hands-on components of a lab are utilized simultaneously.

With today's students so proficient with and dependent upon technology, there is an ever-increasing movement toward technology use in the classroom environment. Science teachers are included in this movement, as the emergence of virtual lab technology in the late 1970s has sparked a debate between the effectiveness of traditional hands-on labs and their virtual counterparts (Abdulwahed & Nagy, 2009; Campbell, 1985). In reviewing the literature, however, there is insufficient empirical evidence supporting the full implementation of virtual laboratory experiments, as reflected in the conclusions drawn by Ma and Nickerson (2006).

Most students preferred face-to-face courses to online courses due to the nature of the lab environment. The students in face-to-face labs had an opportunity to ask questions in real time, and interact with other lab students. The virtual lab participants expressed that the convenience to work on virtual labs at any time was useful, and the ability to begin and pick up labs when necessary was beneficial. Those students in the virtual labs also expressed that they were happy to not have the pressures of immediate responses to instructors. Overall, the face-to-face lab benefits outweighed the virtual lab convenience (Bhargava et al., 2006; Swan & O'Donnell, 2009).

Students generally appeared to be comfortable with the virtual components of lab experiences and reported no difficulties with many of the virtual labs reported in these studies (Bhargava et al., 2006). While students perceived the virtual lab as having the same effectiveness as hands-on labs, some preferred completing a virtual lab prior to a hands-on lab investigation in order to preview the material (Nickerson et. al, 2007; Swan & O'Donnell, 2009). There seems to be a general consensus among researchers that virtual labs should be utilized as a supplement, and not a replacement for traditional hands-on labs (Darrah et al., 2014; Hawkins, 2013; Tatli & Ayas, 2013).

Problem Statement

Although both virtual and hands-on laboratory experiments have their drawbacks, it appears that they both exhibit many positive attributes as well. Students can access virtual labs at any time, so they can go back to the content, which may help in their overall understanding of the science phenomenon being studied. The subject topic variable is also worth noting as some concepts such as gas laws and electron flow may work better with virtual labs so that students may see the molecules and electrons move in a simulated environment. When combined with hands-on components, virtual labs can help preview their physical lab experiences, leading to higher student comfort and confidence in the overall environment. Researchers, however, have noted that virtual labs alone may not be very effective at teaching proper laboratory techniques and procedures (Hawkins, 2013).

Overall, the research indicates that the implementation of virtual labs is rapidly growing. Recent studies suggest that due to financial struggles and cutbacks to science programs, less physical instrumentation is available to students (Darrah et al., 2014). This lack of financial support may pave the way for virtual labs to be at the forefront of the science curriculum at the post-secondary level. Regardless of the growing trend of education becoming accessible online, there is insufficient empirical evidence at this point to support the full implementation of virtual labs. Additional research on student perceptions, attitudes, and interactions with virtual labs as well as student characteristics, such as prior science achievement, may positively impact academic achievement in virtual lab settings and impact both pedagogical methods and student success. As comparative research between the two different laboratory environments continues to reveal the strengths and weaknesses of each, it is safe to say that future research focused on how best to utilize this technological advancement in conjunction with and/or instead of traditional labs, remains unclear.

There have been numerous studies to support a significant relation between GPA and academic achievement (Cassidy & Eachus, 2000; McKensie & Schweitzer, 2001). These studies revealed that the most important factor in predicting academic performance was students' prior academic performance in any subject. Furthermore, there have been several studies to support a significant relation between prior academic performance and science achievement, which is the basis of this study (McCall, Allen, & Fike, 2006; Zeegers, 2004).

Research questions that were investigated in this study are derived from the growing conversation as science education decides on student learning, and the best way to prepare students for future careers in science. The research questions are as follows:

1. To what extent does student performance differ in virtual and hands-on labs?
2. To what extent does prior science achievement contribute to differences in student performance in virtual and hands-on labs?

The first research question investigated students' ability to interact and succeed in both the hands-on and virtual lab settings with emphasis on appropriateness, accuracy, and quality of responses to each question or prompt. This study first tested the hypothesis that students completing virtual labs will outperform their hands-on lab counterparts. The second research question investigated the extent to which prior science achievement, measured by the participants' grade on a general chemistry assessment exam, predicts student academic success in traditional or virtual lab environments. The research tested the hypothesis that post-secondary students with higher science achievement do better in virtual labs than hands-on labs, but lower-achieving students perform better in hands-on labs.

Rationale

Investigation into the influence of virtual lab environment performance would yield results that may help to develop effective approaches to instruction, and inform future pedagogical decisions and creations of new virtual lab experiences. In particular, this study targets the extent to which science achievement influences lab learning. Virtual lab experiments are being integrated into science classrooms, but research has yet to evaluate the effect of prior achievement, which has been shown to predict the effectiveness of other interventions in science. The research will contribute to the enrichment of a currently sparse body of literature and provide quantitative data to substantiate subjective assertions. Findings could motivate the pursuit of future research endeavors in virtual laboratory environments, especially in the chemistry discipline with students of varying achievement. Prospective studies may seek to replicate findings and investigate effects of other predictor variables aside from prior science achievement on the effectiveness of virtual lab environments.

Methods

Participants

The participants in this study were a convenience sample of 70 college students enrolled in six sections of an organic chemistry course at a private four-year college on Long Island, New York. The majority of participants were first-year college students between 18-22 years of age and had completed a general chemistry course in high school within the past three years. A majority of the students were nursing majors who live on Long Island. The participants were taught by the teacher-researcher in the Spring 2018 semester of the 2017-2018 academic year. During the first week of instruction, the teacher-researcher explained the research initiative to all potential subjects and allowed unlimited time for questions. A letter was given to each student requesting permission to participate in the study (see Appendix A). There was neither a reward for participation nor consequence for declining to take part. None so opted. All students, regardless of participation status, were to receive the same instruction and assessments, which would factor into their overall semester grade. Furthermore, no names were included in the study and all students were assigned numbers to protect their identities from the external raters. Of the 70 students enrolled in the six sections of the chemistry course, all 70 provided the requisite consent. None of the students were later removed from the study; therefore, all 70 students were qualified for participation.

Research Design

The study utilized a single-group counterbalanced A-B-A-B experimental design to investigate the influence of prior science achievement on success in virtual and traditional lab experiences. The counterbalanced A-B-A-B design was chosen because it requires two baseline phases and two phases of treatment. If scores revert to the baseline when the independent variable (science achievement) is removed, and if intervention effects are similar during both treatment phases, then the possibility that the effects can be attributed to extraneous variables is greatly reduced (Gay, Mills, & Airasian, 2012). Since a group was created for each possible order, then the variance due to order effects became a separate source of variance. The data for the labs were therefore not weighted.

The study began at the start of the laboratory portion of the course. Participants took an initial pre-test assessment to test students' current knowledge of the laboratory curriculum prior to beginning any of the lab experiments. Also at the beginning of the semester, students took a general chemistry assessment exam to test prior science achievement. Participants then took four post-test assessments that were identical to the pre-test assessment at the end of each of the four labs (whether treatment or control).

The experiment spanned approximately four instructional weeks of laboratory experimentation for the counterbalanced A-B-A-B design. The students alternated between traditional and virtual learning environments. The virtual lab experiments were the treatment group and the experiments originated from the Division of Chemical Education page of the American Chemical Society. The virtual labs were designed to be almost identical to the traditional hands-on laboratory exercises with the only variable being virtual collection of data. The students were assigned to two groups (34 in the first and 36 in the second) based on their self-registered course sections. During the A (first and third) intervals, lesson content was delivered exclusively in the traditional hands-on learning environment for the first group. These periods alternated with the instructional intervention of a virtual lab environment that occurred in the B (second and fourth) intervals. This model and intervals was flipped with the second group of participants, which were of similar demographics.

Table 1

Treatment and Control Schematic For ABAB Research Design

	Interval			
	A	B	A	B
Group 1	C	T	C	T
Group 2	T	C	T	C

Notes. *N*’s for each group were 34 for the first and 36 for the second; C = control; hands-on lab experience; T = treatment; virtual lab experience.

During both periods, students were given the same pre-laboratory introduction where all lesson content was introduced. At the end of each interval, students were tested on their conceptual knowledge of the topic addressed in the laboratory experiment. Scores were compared on both the treatment and control trials to determine the extent to which prior science achievement can best predict whether students succeeded in traditional or virtual lab environments.

Description of Hands-on Lab #1 (Experiment 1): Density

At the beginning of the laboratory period, the instructor lectured students on the concept and properties of density (content) and the use of several pieces of laboratory equipment to collect data (laboratory skills). Students had access to a copy of these notes throughout the lab, along with the lab procedure.

The students followed the procedure first by measuring out 10.0 mL of water in a graduated cylinder and then calculated the mass of the sample on an electronic balance. Students utilized mass and volume to calculate the density of their sample. The participants' calculated density value was then compared to the actual density value of water and a percent error figure was calculated to see the extent of error performed by the students. The participants then completed the same procedure but used ethanol instead of water and again calculated a density value and percent error.

In the second half of the laboratory, the students attempted to calculate the density for two pieces of copper. One piece of copper was a rectangular prism and the other was a cylinder shape. With both pieces of copper, the students measured mass with an electronic scale. With the rectangular prism, students measured length, width, and height to find the volume. With the cylinder shape, students measured volume using the volume displacement method. Theoretically, both pieces of copper, regardless of shape, should have the same density. The participants calculated density values using their measured masses and volumes, and then compared their calculated value to an actual value to calculate a percent error. Students completed a data sheet as they completed the laboratory experiment (see Appendix B, Laboratory 1 Hands-on Procedure and Data).

At the end of the laboratory period, the students put away all lab equipment, safely disposed of all chemical waste, and then completed the post-lab quiz containing ten questions about the content of the experiment and concept (see Appendix C, Lab #1 Post-Test Assessment).

Description of Virtual Lab #1 (Experiment 1): Density

At the beginning of the laboratory period, the instructor lectured students on the concept and properties of density (content). Students had access to a copy of these notes throughout the lab. The students did not have laboratory equipment available to them to complete the lab like in the traditional hands-on procedure. Instead, they only had a computer, calculator, and laboratory procedure (see Appendix D, Virtual Laboratory #1 Procedure).

The students followed the procedure first by reading how to navigate through the density lab simulator to collect readings on various minerals. Students worked through nine different minerals and calculated their densities. First they selected the mineral and clicked “immerse the mineral” to measure the volume of the mineral by using the displacement method. Before and after readings on the graduated cylinder were displayed on the screen for the students. The students then clicked “weigh the mineral” to get an accurate reading of the objects mass in the form of a virtual triple-beam balance. With the use of the given mass and volume, the students calculated the density of the various minerals. Since the students were completing a virtual lab, there was no experimental error, so no percent error was calculated.

In the second half of the laboratory, the students attempted to calculate the density of everyday objects with a slightly different simulator. In this simulator, students dragged the various objects, such as a block of wood, over to an electronic scale and recorded the mass reading on their data sheet. The students clicked and dragged the objects into the cylinder of water and then saw how much volume was displaced. Then the students recorded the mass reading on their data sheet. The students calculated the density using their values for all nine objects. As stated earlier, since there was no experimental error, students did not calculate percent error values for their calculations. Instead, two hypothetical situations were given to the students to calculate density and percent error. Students filled in a data sheet as they completed the laboratory experiment (see Appendix E, Virtual Laboratory #1 Data Sheet).

At the end of the laboratory period, the students turned off the computers and completed the post-lab quiz containing ten questions about the content of the experiment. The post-lab quiz was identical to the one given to the traditional hands-on laboratory group (see Appendix C, Lab #1 Post-Test Assessment).

Description of Hands-on Lab #2 (Experiment 2): Acids and Bases

At the beginning of the laboratory period, the instructor lectured students on the concept and properties of acids, bases, and salts (content) and the use of several pieces of laboratory equipment utilized to collect data (laboratory skills), such as glassware, pH paper, and buffer solutions. Students had access to a copy of these notes throughout the lab, along with the lab procedure (see Appendix F, Hands-on Laboratory #2 Procedure).

The students followed the procedure first by measuring the pH of acids by placing small amounts of solutions in dropper plates and dipping universal indicator paper into the solutions in order to get a pH reading. The students cleaned out their dropper plates and continued the procedure to collect the pH of four bases. Students recorded their pH readings on the data sheet provided.

In the third part of the lab, students focused on indicators. Six indicators were placed into solutions of an acid in a dropper plate. Students noted any color changes with the indicators and the acidic solution. After completing all six indicators, the participants then cleaned out their dropper plates and followed the same procedure using the six indicators but this time with a basic solution. Students wrote down any color changes with the indicators and the basic solution.

In the final part of the lab, students focused on buffer systems. Students created a control group of only water, followed by a buffer solution. The students added small amounts (2 mL) of acid and base to the control and buffer solutions and observed if the pH has changed. If the students created the buffer solutions correctly, the pH of the solutions should have remained constant indicating that the buffer solution had worked. Students filled in a data sheet as they completed the laboratory experiment (see Appendix G, Hands-on Laboratory #2 Data).

At the end of the laboratory period, the students put away all lab equipment, safely disposed of all chemical waste, and then completed the post-lab quiz containing ten questions about the content of the experiment and concept (see Appendix H, Lab #2 Post-Test Assessment).

Description of Virtual Lab #2 (Experiment 2): Acids and Bases

At the beginning of the laboratory period, the instructor lectured students on the concept and properties of acids, base, and salts (content). Students had access to a copy of these notes throughout the lab, along with the lab procedure (see Appendix I, Virtual Laboratory #2 Procedure). The students did not have laboratory equipment available to them to complete the lab like in the traditional hands-on procedure. Instead, they only had a computer, procedure, and data sheet.

The students followed the procedure first by reading how to navigate through the acid and base lab simulator to collect pH readings on acids and bases. Students first experienced the molecules in water noting the red ions as acids (H_3O^+) and the blue ions as bases (OH^-). To test the pH of water, the students clicked and dragged the pH meter into the solution, and they checked the pH using universal indicator paper. Unlike the traditional hands-on lab, the students could view the micro view of the water and the molecules moving. The students tested the pH of a weak acid and strong acid. Just as with the water, to test the pH of the acidic solutions, the students clicked and dragged the pH meter into the solution, and they also checked the pH using universal indicator paper. They followed this procedure one more time with both a strong base and a weak base.

The students used a virtual battery, which showed the conductivity of various solutions. The solutions included the water, strong acid, weak acid, strong base, and weak base. Once the positive and negative ends of the virtual battery were submerged in the various solutions, the students noted if the light bulb lights up or not – indicating conductivity.

In the second part of the lab, students explored various indicators and pH. Here the students were shown picture representations of nine indicators with their colors at various pH values. These were used as the standards for unknown solutions. Each of the links the students clicked on had 13 test tubes containing solutions with pH values from 1 to 13, and 2-4 drops of referenced indicator was added. The students created a table of each of the nine indicators and their colors at the differing pH values. The students then viewed several unknown solutions and determined the approximate pH value based on the color the indicator expresses. The students compared these pictures with the standards given in the first part. Lastly, the students identified the approximate pH of the solutions by clicking a link that showed the solutions dipped in universal indicator paper. The students noted if there was a difference between the indicator pH range and the pH paper.

The last part of the lab explored buffers and pH. This part of the experiment was divided into nine steps. At each step, students were shown a picture of what was performed at each step, such as adding 30 mL of 0.1 M HCl. Students recorded their observations, which included color changes, precipitate formation, evolution of gas, or some similar results.

At the end of the laboratory period, the students turned off the computers and completed the post-lab quiz containing ten questions about the content of the experiment and concept. The post-lab quiz was identical to the one given to the traditional hands-on laboratory group (see Appendix H, Lab #2 Post-Test Assessment).

Description of Hands-on Lab #3 (Experiment 3): Molecular Models

At the beginning of the laboratory period, the instructor lectured students on the various types of isomers (content) and the use of molecular model kits (laboratory skills), which demonstrated the structure and shape of molecules in three-dimensions. Students had access to a copy of these notes throughout the lab, along with the lab procedure (see Appendix J, Hands-On Laboratory #3 Procedure).

The students followed the procedure to construct various molecules beginning with methane, ethane and then propane. Students wrote out the condensed structural formulas, as well as sketched an image of their three-dimensional molecule on the paper. The students continued this process with various types of isomers including structural positional isomers, optical isomers, functional isomers, cis and trans isomers and cyclic compounds. Students filled in a data sheet as they completed the laboratory experiment (see Appendix K, Laboratory Data Sheet for both Hands-on and Virtual Experiments #3).

At the end of the laboratory period, the students put away the molecule kits, and completed the post-lab quiz containing ten questions about the content of the experiment (see Appendix L, Lab #3 Post-Test Assessment).

Description of Virtual Lab #3 (Experiment 3): Molecular Models

Just as with the beginning of the traditional hands-on learning experience, the instructor lectured students on the various types of isomers (content), and the structure and shape of molecules in three-dimension. Students had access to a copy of these notes throughout the lab, along with the lab procedure (see Appendix M, Virtual Laboratory #3 Procedure). The students didn't have a model kit available to them to complete the lab, as in the traditional hands-on procedure.

The students opened up a program called "Build a Molecule" from Phet Interactive Simulations and followed a procedure constructing the same molecules constructed using the model kits, only on a computer screen.

Students wrote out the condensed structural formulas, as well as sketched an image of their three-dimensional molecule on paper. This part of the process will be the same for both the hands-on and virtual learning experiences. The students then continued this process with various types of isomers including structural positional isomers, optical isomers, functional isomers, cis and trans isomers and cyclic compounds. Students filled in a data sheet as they completed the laboratory experiment (see Appendix K, Laboratory Data Sheet for both Hands-on and Virtual Experiments #3).

At the end of the laboratory period, the students turned off the computers and completed the post-lab quiz containing ten questions about the content of the experiment. The post-lab quiz was identical to the one given to the traditional hands-on laboratory group (see Appendix L, Lab #3 Post-Test Assessment).

Description of Hands-on Lab #4 (Experiment 4): Solubility

At the beginning of the laboratory period, the instructor lectured students on the concept and properties of solubility and conductivity (content) and the use of several pieces of laboratory equipment utilized to collect data (laboratory skills), such as glassware and a conductivity meter. Students had access to a copy of these notes throughout the lab, along with the lab procedure (see Appendix N, Hands-on Laboratory #4 Procedure).

The students first followed the procedure by dissolving small amounts of an organic solute, salicylic acid, in a test tube with an organic solvent, methanol. The students then tried to dissolve small amounts of an inorganic solute, sodium chloride, in a test tube with the organic solvent, methanol. Theoretically, students should have observed that organic solvents dissolve organic compounds, while organic solvents do not dissolve inorganic compounds. Students recorded their observations on the data sheet provided, (see Appendix O, Laboratory #4 Data Sheet for Hands-on Experiment).

In the second part of the procedure, the students dissolved small amounts of an organic solute, salicylic acid, in a test tube with an inorganic solvent, water. The students then tried to dissolve small amounts of an inorganic solute, sodium chloride, in a test tube with the inorganic solvent, water. Theoretically, students should observe that inorganic solvents dissolve inorganic compounds, but not organic compounds. Again, students recorded their observations on the data sheet provided.

In the last part of the procedure, the students decided whether certain solutions conduct electricity or not using a conductivity meter that was placed into three different samples. The samples consisted of pure distilled water, sodium chloride dissolved in water, and salicylic acid in methanol. Observations were recorded on the data sheet provided.

At the end of the laboratory period, the students put away all lab equipment, safely disposed of all chemical waste, and then completed the post-lab quiz containing ten questions about the content of the experiment and concept (see Appendix P, Lab #4 Post-Test Assessment).

Description of Virtual Lab #4 (Experiment 4): Solubility

At the beginning of the laboratory period, the instructor lectured students on the concept of solubility and conductivity (content). Students had access to a copy of these notes throughout the lab, along with the lab procedure (see Appendix Q, Virtual Laboratory #4 Procedure). The students did not have laboratory equipment available to them to complete the lab as in the traditional hands-on procedure. Instead, they only had a computer, procedure, and data sheet (see Appendix R, Virtual Laboratory #4 Data Sheet).

The students followed the procedure by watching a video on polar and nonpolar solutes and solvents first. The video showed students how nonpolar, or organic, solvents dissolved nonpolar, or organic, solutes. The video also showed students how nonpolar, or organic, solvents did not dissolve polar, or inorganic, solutes. The students then answered a few short answer questions and filled in the table on the data sheet provided.

In the second part of the procedure, the students followed a second link to further explore solubility and conductivity. The students clicked and dragged a saltshaker downward to add sodium chloride (NaCl) to the water. The students noted the way the Na^+ and Cl^- moved in solution as they dissolved. The students clicked the "water" tab on the top left of the simulation and noted the water's activity. They then clicked and dragged the salt (sodium chloride) into the water and observed the ions in water. The same two procedures were followed for sugar.

In the last part of the procedure, the students again clicked and dragged the saltshaker downward to add sodium chloride (NaCl) to the water. This time, they dragged the conductivity meter on the right side of the simulation into the water and saw if the solution conducted electricity. Then the same procedure was followed using the sugar instead of salt.

At the end of the laboratory period, the students turned off the computers and completed the post-lab quiz containing ten questions about the content of the experiment and concept. The post-lab quiz was identical to the one given to the traditional hands-on laboratory group (see Appendix P, Lab #4 Post-Test Assessment).

Variables and Measures

Previous Science Achievement. In order to account for possible variance in the virtual and hands-on lab settings attributed to previous science achievement, students took a general chemistry exam to assess their knowledge in the general chemistry field (see Appendix S, General Chemistry Assessment Exam). The general chemistry assessment has been previously utilized in this course to measure prior chemistry knowledge. This can inform instructors on how to effectively approach instruction, and pedagogical decisions for the semester. The assessment was a 40 question multiple choice style exam that covered topics from general chemistry including atomic concepts, molar mass, chemical bonding, solutions, stoichiometry, and balancing equations. The assessment questions were modeled after New York State Chemistry Regents questions on these topics. Students took this exam during the first laboratory meeting.

The students had an hour to complete the assessment, and the teacher-researcher administered the exam. This was the first semester the students were taking the course with the teacher-researcher. This was the variable in the analysis as a measure of previous science achievement.

Gender and Age. In the study, a majority of the participants were female (65 out of 70; 92.9%) and first-year college freshman (61 out of 70; 87.1%). Therefore, gender and age were not entered as covariates.

Pre-test Assessment. The function of the pre-test assessment measure was to address the research questions and evaluate the students' knowledge prior to the treatments. The pre-test assessment was a 40-item multiple-choice style quiz on four topics that the laboratory experiments focused on (see Appendix T, Pre-Test Assessment). The assessment aligned with the topics and activities that were performed in each of the four lab experiments. Assessment questions focused on content specific knowledge and not proper laboratory etiquette, equipment and techniques, which were not formally covered in the virtual lab environment. Assessment questions were also aligned with the topics and concepts covered in the lecture portion of the course, as well as the textbook administered to the students. The students had an hour to complete the assessment, and the teacher-researcher administered the exam. Each correct response received a score of one and student scores were calculated out of 40. Pre-test assessment scores were compared with post-test assessment scores to create an effectiveness coefficient, or gain score.

Post-test Assessments. The function of the post-test assessment measure was to address the research questions and evaluate the students' knowledge after the treatment phases. The four post-test assessments were 10-item multiple-choice style quizzes on the content of each laboratory experiment. Post-test question items were the same as the pre-test assessment questions. Just as in the pre-test, assessment questions focused on content specific knowledge and not proper laboratory etiquette, equipment, and techniques. The post-test assessments were given to both the treatment and control groups at the end of the laboratory period. The students had twenty minutes to complete the four assessments, and the teacher-researcher administered the exam. Each correct response was given a score of one and student scores were calculated out of 10 (see Appendix C, H, L, and P, four post-test assessments). Post-test assessment scores were compared with pre-test assessment to create an effectiveness coefficient, or gain score.

Data Collection Procedure

Data was collected from the pre- and post-tests at the beginning of the semester and at the end of each laboratory experiment. Data was also collected from the prior science achievement assessment at the beginning of the semester. Data was then collected at the end of each of the four laboratory experiments of the study.

With the prior science achievement assessment exam, final scores were a summation of all response scores for a possible point range of 0-40. The students had an hour to complete the assessment, and the teacher-researcher administered the exam. With the pre-lab assessment, again final scores were a summation of all response scores for a possible point range of 0-40. The students had an hour to complete the assessment, and the teacher-researcher administered the exam. The students’ scores were entered into a Microsoft Excel file that was then uploaded and entered into an SPSS program (Version 25.0) for analysis and coding.

With the four post-lab quizzes, final scores were a summation of all response scores with a possible point range of 0-10 on both the treatment and control quizzes for each laboratory experiment. The students’ total score for both the treatment and control phases were entered into a Microsoft Excel file that was again uploaded into the SPSS program for analysis. The post-lab quiz was identical to the one given to the traditional hands-on laboratory group.

Results

To ensure that the four labs of this study were statistically comparable, a counterbalanced ABAB design was employed. The counterbalanced method controlled the order effects in the repeated measures design. The variables in this study were previous science achievement, along with the pre- and post-test assessments following each laboratory period. Analyses focused on participants' pre- and post-test scores on various hands-on and virtual lab experiments were collected in both the treatment and control phases. While informally speaking with students, it appears that the students were relatively comfortable with virtual lab experimentation and had no trouble handling the computer equipment needed to collect data. There was no observed difference in students' performance and execution of lab experimentation regardless of hands-on or virtual collection of data. Neither did students voice a preference or any difficulty with either method of instruction. Of the 70 students enrolled in the six sections of the chemistry course, all 70 gave the requisite consent. There was neither a reward for participation nor consequence for declining to take part. None so opted. None of the students were later removed during the course of the study; therefore, all 70 students were qualified for participation.

To test the hypothesis that virtual labs were more effective than hands-on lab experiences, the scores of the treatment phases were compared with the control phases for each lab. The mean of the control scores were subtracted from the mean of the treatment scores to obtain the effectiveness coefficient scores, or gain scores, which were used as an outcome variable for a t-test analysis. A t-test analysis was completed on each of the four laboratory experiments, as well as an aggregate analysis including all four laboratory assessment scores.

To test the hypothesis that high-achieving students would outperform low-achieving students on virtual labs, students were coded into two groups for a MANOVA analysis. Students' scores on the prior science achievement assessment were used to evaluate and assign student achievement levels appropriately.

The results section includes descriptive statistics of previous science achievement, the pre- and post-test assessments, as well as gain scores. The section later includes findings from several t-test and MANOVA analyses.

Descriptive Statistics

Previous Science Achievement

Frequency statistics were calculated for the previous science achievement content tests (Table 2). In order to investigate the effect of prior science achievement on virtual or hands-on laboratory experiments, students were coded into two groups for a MANOVA analysis. Students' scores on the prior science achievement assessment were used to evaluate and assign student achievement levels appropriately. To classify students appropriately, the mean and standard deviation of each previous science achievement grades were obtained using an SPSS program (Version 25.0). The mean and standard deviation of each prior science achievement exam were calculated ($M = 22.53$, $SD = 5.93$). In this dichotomous model, students with scores below 23 were coded as low-achieving ($n = 34$) and students with scores above or equal to 23 were coded as high-achieving ($n = 36$). The mean was utilized to create the middle value for separating high- and low-achieving students. Science achievement groupings were created so that the effect of previous science achievement could be utilized to predict success in the hands-on and virtual lab environments.

The mean and standard deviation values were calculated for the overall content tests (*M* = 22.95, *SD* = 3.50). The mean and standard deviation values were also calculated for the content tests showing high-achieving students (*M* = 27.81, *SD* = 4.15) and low-achieving students (*M* = 18.09, *SD* = 3.02).

Table 2

Descriptive Statistics for Previous Science Achievement, Overall and by Group

Variables	*n*	*M*	*SD*	Min	Max	Range	SE
Overall	70	22.95	3.50	12.0	37.0	25.0	.81
High	36	27.81	4.15	23.0	37.0	14.0	.75
Low	34	18.09	3.02	12.0	22.0	10.0	.52

Note. High = high-achieving students; Low = low-achieving students.

Pre-Test Assessment

Descriptive statistics were computed for the eight hands-on and virtual lab pre-test scores (Table 3). The mean and standard deviation values were calculated for the combined hands-on lab #1 (*M* = 5.28, *SD* = 1.75), virtual lab #1 (*M* = 5.08, *SD* = 1.66), hands-on lab #2 (*M* = 5.05, *SD* = 1.50), virtual lab #2 (*M* = 5.12, *SD* = 2.07), hands-on lab #3 (*M* = 3.72, *SD* = 1.92), virtual lab #3 (*M* = 4.05, *SD* = 1.59), hands-on lab #4 (*M* = 3.73, *SD* = 1.98), and virtual lab #4 (*M* = 4.70, *SD* = 2.11).

The means and standard deviation values were calculated for the high- and low-achieving students' hands-on lab #1, virtual lab #1, hands-on lab #2, virtual lab #2, hands-on lab #3, virtual lab #3, hands-on lab #4, the virtual lab #4 (Table 3).

Table 3

Descriptive Statistics for Pre-Test in Virtual and Hands-on Labs, Overall and by Group

Variables	n	*M*	*SD*	Min	Max	Range	SE
High-Achieving							
HOL Lab #1	20	6.05	2.83	1.0	10.0	9.0	.94
VTL Lab # 1	16	5.56	2.01	3.0	10.0	7.0	.67
HOL Lab # 2	16	6.20	2.00	3.0	9.0	6.0	.67
VTL Lab # 2	20	6.11	2.80	1.0	10.0	9.0	.93
HOL Lab # 3	20	4.44	1.88	.0	6.0	6.0	.63
VTL Lab # 3	16	3.89	1.45	2.0	6.0	4.0	.48
HOL Lab # 4	16	4.45	2.19	1.0	7.0	6.0	.73
VTL Lab # 4	20	5.01	2.06	1.0	8.0	7.0	.69
HOL Overall	36	5.29	2.45	.0	10.0	10.0	.88
VTL Overall	36	5.14	2.52	1.0	10.0	9.0	.93
Low-Achieving							
HOL Lab #1	16	4.50	2.61	.0	8.0	8.0	.93
VTL Lab # 1	18	4.60	1.78	1.0	6.0	5.0	.56
HOL Lab # 2	18	3.90	1.37	1.0	6.0	5.0	.43
VTL Lab # 2	16	4.13	2.59	.0	8.0	8.0	.91
HOL Lab # 3	16	3.00	1.31	.0	4.0	4.0	.46
VTL Lab # 3	18	4.20	1.03	2.0	6.0	4.0	.33
HOL Lab # 4	18	3.00	2.31	.0	8.0	8.0	.73
VTL Lab # 4	16	4.38	1.41	1.0	5.0	4.0	.50
HOL Overall	34	3.60	2.05	.0	8.0	8.0	.76
VTL Overall	34	4.33	2.22	.0	8.0	8.0	.49
Overall							

HOL Lab #1	36	5.28	1.75	.0	10.0	10.0	.60
VTL Lab # 1	34	5.08	1.66	1.0	10.0	9.0	.71
HOL Lab # 2	34	5.05	1.50	1.0	9.0	8.0	.59
VTL Lab # 2	36	5.12	2.07	.0	10.0	10.0	.73
HOL Lab # 3	36	3.72	1.92	.0	6.0	6.0	.44
VTL Lab # 3	34	4.05	1.59	2.0	6.0	4.0	.70
HOL Lab # 4	34	3.73	1.98	.0	8.0	8.0	.48
VTL Lab # 4	36	4.70	2.11	1.0	8.0	7.0	.56

Note. High-Achieving = high-achieving students; Low-Achieving = low-achieving students; VTL = virtual laboratory experiments; HOL = hands-on laboratory experiments.

Post-Test Assessment

Descriptive statistics were also run for the eight hands-on and virtual lab post-lab scores (Table 4). The mean and standard deviation values were calculated for the combined hands-on lab #1 (*M* = 8.39, *SD* = 1.78), virtual lab #1 (*M* = 8.38, *SD* = 1.90), hands-on lab #2 (*M* = 8.01, *SD* = 2.07), virtual lab #2 (*M* = 8.15, *SD* = 2.14), hands-on lab #3 (*M* = 6.78, *SD* = 1.84), virtual lab #3 (*M* = 7.24, *SD* = 1.94), hands-on lab #4 (*M* = 7.31, *SD* = 2.10), and virtual lab #4 (*M* = 7.16, *SD* = 1.59). Mean and standard deviation values were also obtained for each individual lab based on prior science achievement.

The means and standard deviation values were calculated for both the high- and low-achieving students' hands-on lab #1, virtual lab #1, hands-on lab #2, virtual lab #2, hands-on lab #3, virtual lab #3, hands-on lab #4, and virtual lab #4 (Table 4).

Table 4

Descriptive Statistics for Post-Test in Virtual and Hands-on Labs, Overall and by Group

Variables	n	*M*	*SD*	Min	Max	Range	SE
High-Achieving							
HOL Lab #1	20	8.78	1.20	7.0	10.0	3.0	.40
VTL Lab # 1	16	8.56	1.51	6.0	10.0	4.0	.50
HOL Lab # 2	16	8.22	1.79	4.0	10.0	6.0	.60
VTL Lab # 2	20	8.67	1.12	7.0	10.0	3.0	.37
HOL Lab # 3	20	7.56	1.01	6.0	9.0	3.0	.34
VTL Lab # 3	16	7.67	1.41	6.0	10.0	4.0	.47
HOL Lab # 4	16	7.22	1.20	5.0	9.0	4.0	.40
VTL Lab # 4	20	7.44	.73	7.0	9.0	2.0	.24
HOL Combined	36	7.95	1.67	4.0	10.0	6.0	.78
VTL Combined	36	8.09	1.80	6.0	10.0	4.0	.56
Low-Achieving							
HOL Lab #1	16	8.00	1.31	6.0	10.0	4.0	.46
VTL Lab # 1	18	8.20	.79	8.0	10.0	2.0	.25
HOL Lab # 2	18	7.79	1.10	6.0	10.0	4.0	.35
VTL Lab # 2	16	7.62	1.19	6.0	10.0	4.0	.42
HOL Lab # 3	16	6.00	2.39	1.0	9.0	8.0	.85
VTL Lab # 3	18	6.80	1.62	3.0	9.0	6.0	.51
HOL Lab # 4	18	7.40	1.90	3.0	9.0	6.0	.60
VTL Lab # 4	16	6.88	1.46	5.0	9.0	4.0	.51
HOL Combined	34	7.30	1.97	1.0	10.0	9.0	.81
VTL Combined	34	7.38	2.04	3.0	10.0	7.0	.72
Overall							
HOL Lab #1	36	8.39	1.78	6.0	10.0	4.0	.70

VTL Lab # 1	34	8.38	1.90	6.0	10.0	4.0	.65
HOL Lab # 2	34	8.01	2.07	4.0	10.0	6.0	.85
VTL Lab # 2	36	8.15	2.14	6.0	10.0	4.0	.62
HOL Lab # 3	36	6.78	1.84	1.0	9.0	8.0	.73
VTL Lab # 3	34	7.24	1.94	3.0	10.0	7.0	.88
HOL Lab # 4	34	7.31	2.10	3.0	9.0	6.0	.61
VTL Lab # 4	36	7.16	1.59	5.0	9.0	4.0	.71

Note. High-Achieving = high-achieving students; Low-Achieving = low-achieving students; VTL = virtual laboratory experiments; HOL = hands-on laboratory experiments.

Gain Scores

Descriptive statistics were computed for the eight hands-on and virtual lab gain scores (Table 5). The mean and standard deviation values were calculated for the combined hands-on lab #1 (M = 3.70, SD = 2.21), virtual lab #1 (M = 3.68, SD = 1.56), hands-on lab #2 (M = 2.57, SD = 1.86), virtual lab #2 (M = 2.54, SD = 1.99), hands-on lab #3 (M = 3.06, SD = 2.11), virtual lab #3 (M = 3.51, SD = 2.06), hands-on lab #4 (M = 3.59, SD = 1.65), and virtual lab #4 (M = 5.18, SD = 1.78). Mean and standard deviation values were also obtained for each individual lab based on prior science achievement.

The means and standard deviation values were calculated for the high- and low-achieving students' hands-on lab #1, virtual lab #1, hands-on lab #2, virtual lab #2, hands-on lab #3, virtual lab #3, hands-on lab #4, the virtual lab #4 (Table 5).

Table 5

Descriptive Statistics for Gain Scores in Virtual and Hands-on Labs, Overall and by Group

Variables	n	*M*	*SD*	Min	Max	Range	SE

High-Achieving							
HOL Lab #1	20	4.20	1.74	2.0	8.0	6.0	.39
VTL Lab # 1	16	3.11	2.31	.0	7.0	7.0	.77
HOL Lab # 2	16	2.22	1.86	.0	5.0	5.0	.62
VTL Lab # 2	20	2.44	2.19	.0	6.0	6.0	.73
HOL Lab # 3	20	3.11	1.69	1.0	6.0	5.0	.56
VTL Lab # 3	16	3.78	1.79	1.0	6.0	5.0	.60
HOL Lab # 4	16	2.78	1.72	.0	6.0	6.0	.57
VTL Lab # 4	20	2.67	2.00	.0	6.0	6.0	.67
HOL Combined	36	3.08	1.95	.0	8.0	8.0	.89
VTL Combined	36	3.00	2.08	.0	7.0	7.0	.67
Low-Achieving							
HOL Lab #1	16	3.20	2.31	.0	7.0	7.0	.52
VTL Lab # 1	18	4.24	1.99	2.0	8.0	6.0	.63
HOL Lab # 2	18	2.91	1.60	1.0	5.0	4.0	.50
VTL Lab # 2	16	2.63	1.60	.0	5.0	5.0	.56
HOL Lab # 3	16	3.01	1.31	1.0	5.0	4.0	.46
VTL Lab # 3	18	3.24	1.55	1.0	6.0	5.0	.49
HOL Lab # 4	18	4.40	2.46	.0	9.0	9.0	.78
VTL Lab # 4	16	2.51	1.60	1.0	5.0	4.0	.57
HOL Combined	34	3.38	1.96	.0	9.0	9.0	.80
VTL Combined	34	3.16	2.09	.0	8.0	8.0	.77
Overall							
HOL Lab #1	36	3.70	2.21	.0	8.0	8.0	.48
VTL Lab # 1	34	3.68	1.56	.0	8.0	8.0	.69

HOL Lab # 2	34	2.57	1.86	.0	6.0	6.0	.74
VTL Lab # 2	36	2.54	1.99	.0	6.0	6.0	.81
HOL Lab # 3	36	3.06	2.11	1.0	6.0	5.0	.48
VTL Lab # 3	34	3.51	2.06	1.0	6.0	5.0	.66
HOL Lab # 4	34	3.59	1.65	.0	9.0	9.0	.71
VTL Lab # 4	36	5.18	1.78	.0	6.0	6.0	.80

Note. High-Achieving = high-achieving students; Low-Achieving = low-achieving students; VTL = virtual laboratory experiments; HOL = hands-on laboratory experiments.

Correlations

Correlation statistics were calculated for the scores on the combined hands-on and virtual labs as a function of the dichotomous previous science achievement design (Table 6). Intercorrelations for the participants on the combined hands-on and virtual labs for the high-achieving and low-achieving students are presented about and below the diagonal. For all scales, higher coefficients are indicative of stronger associations. Moderate correlations were found amongst the dependent variables in all correlation matrices.

Table 6

Correlations of Performance Scores in Combined Labs, by Lab Type and Group Labs

	HOL Combined Labs: High Ach.	VTL Combined Labs: High Ach.	HOL Combined Labs: Low Ach.	VTL Combined Labs: Low Ach.
HOL Combined Labs: High Ach.	-	.33	.49*	.24
VTL Combined Labs: High Ach.		-	-.28	.29

HOL Combined Labs: Low Ach.			-	.34*
VTL Combined Labs: Low Ach.				-

Note. HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
*$p < .01$.

Correlation statistics were then calculated for the scores on the hands-on and virtual lab #1 as a function of previous science achievement (Table 7). Intercorrelations for the participants on the hands-on and virtual lab #1 for the high-achieving and low-achieving students are presented above the diagonal.

Table 7

Correlations of Performance Scores on Lab # 1, by Lab Type and Group

	HOL Lab # 1: High Ach.	VTL Lab # 1: High Ach.	HOL Lab # 1: Low Ach.	VTL Lab # 1: Low Ach.
HOL Lab # 1: High Ach.	-	.47*	-.12	-.20
VTL Lab # 1: High Ach.		-	.25	-.13
HOL Lab # 1: Low Ach.			-	.30
VTL Lab # 1: Low Ach.				-

Note. HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
*$p < .01$.

Correlation statistics were later calculated for the scores on the hands-on and virtual lab #2 as a function of previous science achievement (Table 8). Intercorrelations for the participants on the hands-on and virtual lab #2 for the high-achieving and low-achieving students are presented above the diagonal.

Table 8

Correlations of Performance Scores on Lab # 2, by Lab Type and Group

	HOL Lab # 2: High Ach.	VTL Lab # 2: High Ach.	HOL Lab # 2: Low Ach.	VTL Lab # 2: Low Ach.
HOL Lab # 2: High Ach.	-	.41	.26*	-.33
VTL Lab # 2: High Ach.		-	.29	-.19
HOL Lab # 2: Low Ach.			-	.30
VTL Lab # 2: Low Ach.				-

Note. HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
*$p < .01$.

Correlation statistics were calculated for the scores on the hands-on and virtual lab #3 as a function of previous science achievement (Table 9). Intercorrelations for the participants on the hands-on and virtual lab #3 for the high-achieving and low-achieving students are presented above the diagonal.

Table 9

Correlations of Performance Scores on Lab # 3, by Lab Type and Group

	HOL Lab # 3: High Ach.	VTL Lab # 3: High Ach.	HOL Lab # 3: Low Ach.	VTL Lab # 3: Low Ach.
HOL Lab # 3: High Ach.	-	.44*	.41	.11*

VTL Lab # 3: High Ach.		-	.30*	-.22
HOL Lab # 3: Low Ach.			-	-.14
VTL Lab # 3: Low Ach.				-

Note. HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
**p* < .01.

Correlation statistics were then completed for the scores on the hands-on and virtual lab #4 as a function of previous science achievement (Table 10). Intercorrelations for the participants on the hands-on and virtual lab #4 for the high-achieving and low-achieving students are presented above the diagonal.

Table 10

Correlations of Performance Scores on Lab # 4, by Lab Type and Group

	HOL Lab # 4: High Ach.	VTL Lab # 4: High Ach.	HOL Lab # 4: Low Ach.	VTL Lab # 4: Low Ach.
HOL Lab # 4: High Ach.	-	.44	.23*	.13
VTL Lab # 4: High Ach.		-	.32*	-.10
HOL Lab # 4: Low Ach.			-	.28*
VTL Lab # 4: Low Ach.				-

Note. HOL = hands-on laboratory experiments; VTL = virtual laboratory experiments; High Ach. = high-achieving students; Low Ach. = low-achieving students
**p* < .01.

Inferential Statistics

Research Question One: Comparisons of Hands-on and Virtual Labs

To test the hypothesis that virtual labs were more effective than hands-on lab experiences, the scores of the treatment phases were compared with the control phases for each lab. The mean of the control scores were subtracted from the mean of the treatment scores to obtain the effectiveness coefficient scores, or gain scores, which were used as an outcome variable for t-test analyses. A paired samples t-test was performed comparing the combined gain scores for the four combined hands-on and virtual labs. Independent t-tests were then performed on each of the four hands-on and virtual labs. There were a total of five t-test analyses comparing hands-on and virtual lab experimentation. For all independent and paired samples t-test analyses, independent observations, and normality were all met.

For the paired samples t-test, no significant difference was found between the combined hands-on (M = 6.26, SD = 2.81) and the combined virtual gain scores (M = 6.24, SD = 3.05), $t(69) = 0.03$, $p = .98$; Shapiro-Wilk's Lambda, $p = .42$. These results suggest that student performance did not differ between the hands-on and virtual environments.

Four independent samples t-tests were then performed comparing the gain scores for each of the four hands-on and virtual labs. Shapiro-Wilk's results were satisfactory for all t-test analyses. No significant difference was found between the hands-on lab #1 gain score (M = 3.09, SD = 1.99) and the virtual lab #1 gain score (M = 3.44, SD = 1.97), $t(33) = -.86$, $p = .40$; Shapiro-Wilk's Lambda, $p = .32$. A lack of significant difference was found between the hands-on lab #2 gain score (M = 2.62, SD = 1.67) and the virtual lab #2 gain score (M = 2.26, SD = 1.56), $t(33) = .90$, $p = .37$; Shapiro-Wilk's Lambda, $p = .11$. No significant difference was found between the hands-on lab #3 gain score (M = 3.38, SD = 1.56) and the virtual lab #3 gain score (M = 4.00, SD = 1.79), $t(33) = -1.41$, $p = .17$; Shapiro-Wilk's Lambda, $p = .38$. Lastly, significant differences were not found between the hands-on lab #4 gain score (*M* = 3.47, *SD* = 2.09) and the virtual lab #4 gain score (*M* = 2.82, *SD* = 1.98), $t(33) = 1.33$, $p = .19$; Shapiro-Wilk's Lambda, $p = .18$. These results suggest that student performance did not differ between the hands-on and virtual environments for each of the four labs.

Research Question Two: Effect of Prior Science Achievement on Performance in HOL and VTL Labs

A multivariate analysis of variance was carried out to assess the extent to which previous science achievement influenced student performance in the traditional hands-on and virtual laboratory environments. The between-subjects factor comprised two groups: students who were identified as high-achieving and students who were identified as low-achieving. In this model, students with scores below 23 were coded as low-achieving ($n = 34$) and students with scores above or equal to 23 were coded as high-achieving ($n = 36$). The dependent variables comprised scores on the hands-on and virtual lab experiences. Evaluations of homogeneity of variance matrices and equality of variance were satisfactory, and moderate correlations were found amongst the dependent variables. Statistical difference was obtained in favor of high-achieving students on the virtual lab experiences, $F(1,68) = 2.80$, $p < .05$; Wilk's Lambda = .26; partial $\eta^2 = .42$). These results suggest that student performance differed between virtual lab environments in favor of the high-achieving students, as opposed to the low-achieving students. These results also suggest that student performance did not differ between the high- and low-achieving students on hands-on lab environments. The effect of previous science achievement on the high-achieving and low-achieving student populations produced effect sizes ($d = 1.70$ and $d = 1.23$, respectively) that exceed Cohen's (1988) convention for a large effect ($d = .80$).

Effect sizes were obtained to give a more profound understanding of how substantive the impact of the treatment was on the virtual labs, and how it varied among students of various levels of achievement. Partial η^2 values were collected for the MANOVA and converted to Cohen's d (Lenhard & Lenhard, 2016). Partial η^2 values are the proportion of variance associated with the main effects, errors or interactions in the four multiple analyses of variances of the study. Effect sizes were evaluated as small, medium, or large based on Cohen's (1992) index of values.

To test the hypothesis that virtual labs were more effective than hands-on lab experiences for high-achieving students, the scores of the treatment phases were compared with the control phases for the hands-on and virtual labs. The mean of the control scores were subtracted from the mean of the treatment scores to obtain the effectiveness coefficient scores, or gain scores, which were used as an outcome variable for t-test analyses. To test the hypothesis that virtual labs were as effective as hands-on lab experiences for low-achieving students, gain scores were utilized to compare treatment and control groups for both lab environments. For both paired samples t-test analyses, independent observations, and normality were all met.

For the first paired samples t-test, a significant difference was found between the gain scores of the hands-on (M = 3.00, SD = 2.08) and the virtual gain scores (M = 3.38, SD = 2.09) for high-achieving students, $t(35) = 0.11$, $p = .01$; Shapiro-Wilk's Lambda, $p = .30$. These results suggest that student performance differed in favor of the virtual lab experimentation for the high-achieving students. For the second paired samples t-test, no significant difference was found between the gain scores of the hands-on (M = 3.19, SD = 1.96) and the virtual gain scores (M = 3.16, SD = 2.09) for low-achieving students, $t(34) = 0.31$, $p = .49$; Shapiro-Wilk's Lambda, p =

.55. These results suggest that student performance did not differ between the hands-on and virtual lab environments for the low-achieving students.

Table 11

Gain Scores for Previous Science Achievement, by Group

	High Ach.	*Low Ach.*
HOL Gain	3.00	3.19
VTL Gain	3.38	3.18

Note. High-Ach. = high-achieving students; Low-Ach. = low-achieving students; HOL Gain = hands-on lab gain scores; VTL Gain = virtual lab gain scores.

Discussion

The purpose of this study was to investigate the extent to which previous science achievement influences students' performance on hands-on and virtual lab performance, and to explore how this influence differs among students of previous science achievement. The hypothesis of the study stated that the implementation of virtual labs would positively influence student achievement in these lab environments, and that the effect of virtual labs would benefit high-achieving students relative to low-achieving students.

The first research question of this study was designed to investigate possible differences in learning achievement in the hands-on and virtual lab environments. The data revealed that students did not perform significantly better in either of these lab experimental environments, which suggests that the interventions were comparably effective for students. Students learned the given material at about the same level of proficiency no matter which laboratory experiment was employed. The only difference in design of the lab material was the collection of data. For example, in the hands-on labs, students collected data with the use of beakers and other glassware, chemicals, and other equipment. In the virtual labs, students collected data virtually with the use of the computer and simulation software. This finding was supported by the literature, as many studies found no difference in effectiveness between virtual and hands-on labs (Darrah et al., 2014; Hawkins, 2013; Tatli & Ayas, 2012; Tatli & Ayas, 2013; Zacharia & Constantinou, 2008). This suggests that hands-on and virtual labs can be used interchangeably to save on costs of chemicals, glassware, etc.

The second research question of this study investigated the extent to which previous science achievement influenced student learning in both the hands-on and virtual environments and how varying levels of previous science achievement impacted the effect of the intervention. The high-achieving students performed significantly better on the virtual lab experiments as opposed to the hands-on experimentation. In other words, the high-achieving students thrived in the virtual lab environment as opposed to the low-achieving students. A possible explanation of high-achieving students succeeding in the virtual lab environment may be due to the fact that the students did not have to worry about the lab procedure (for example, mixing and pouring the chemicals). Instead, they were able to focus on the content itself, where high-achieving students usually succeed academically. Effect size calculations in this design revealed large effects of student learning within the total population and the two achievement groups therein.

The four laboratory experiments spanned across various general and organic chemistry concepts. The largest difference in gain scores for both the high and low-achieving students was found with the molecular modeling lab. Molecules can’t be visualized by the naked eye and therefore students may have trouble grasping the concept. With the molecular modeling lab, the students were able to see three dimensional versions of various molecules they constructed. This allowed them to examine the various shapes and bonds that form when atoms bond together.

Computer use in laboratory settings has increased over the past 50 years as most instrumentation has become automated and most data acquisition that is done in most modern labs requires computers (Hawkins 2013). The use of computers in chemistry labs is evident by the use of simple graphing using spreadsheets, the use of probes to collect real-time data on computers, the use of computers to simulate molecular structures in organic chemistry with programs like ChemDraw and Spartan, and in many other aspects involving presentation and data analysis. Most science labs now include some use of computers. The use of computers varies from the use of spreadsheets to the virtual simulation of labs on a computer. Recently these virtual labs have garnered a lot of attention as online high schools and colleges seek ways to offer science courses online.

Colleges and schools need to have dedicated lab space in order to allow all the students to have lab in smaller groups. Most labs can only have about 25 to 30 students in them at one time, so this means that this space must be used constantly. Virtual labs offer opportunities to lower the costs of the lab due to less operating cost and the use of fewer chemicals. This does not mean that virtual labs come at no cost, since the up-keep of computers and equipment is still costly. Another reason that many schools are deciding to use virtual labs is the possibility of an increase in student population from on-line students. As enrollment in online courses keeps increasing, many schools are using online classes to increase their student enrollment and their funding. Online classes are beneficial because one professor can proctor a class of many students, which decreases teaching expenses, as well as decreases the amount of facilities necessary to carry out classes.

Due to the sample participants in this study, there were no covariates in this study. The only independent variable in this study was prior science achievement. Since there were no covariates, such as gender and age, the t-test and MANOVA analyses could evaluate whether the means of the dependent variables, achievement on the hands-on or virtual labs, were equal across levels of the categorical independent variable. There was no variance due to covariates; therefore, an analysis of covariance model was not utilized.

Implications and Recommendations

Virtual lab learning has profound implications for science instruction and curriculum. The results of this study suggest that student performances in hands-on and virtual lab environments did not differ; therefore virtual lab experiments are an effective tool to consider for science instructional practices. However, it is noteworthy to recognize that there were significant differences between high- and low-achieving students from the MANOVA analysis.

Findings suggest that the use of virtual labs does not harm science achievement and may conserve resources, including glassware, chemicals and other equipment for labs. It is important to note, however, that virtual lab environments do have costs such as purchasing the programs and IT costs. Regardless, school districts appear to be eager to include virtual lab environments in schools as students are engulfed with technology in their lives in and out of school. This appears to be a good direction for schools with an abundance of high-achieving students since they outperformed low-achieving students; however, as stated earlier it may expand the gap between high- and low-achieving students in the science laboratory.

The addition of virtual labs would benefit student learning for high-achieving students. If schools do not want to completely abandon traditional hands-on labs, then these virtual labs may be utilized as a supplement if added to curricula. Accordingly, it is important that subsequent activities of a virtual lab lesson be connected and relevant to the direction of learning and instructional goals. In this experiment, each concept that was introduced in lab was introduced to the students the previous lecture class to ensure the students were exposed to the materials. In science education it is traditional to see the content being learned in the lecture and then reinforced in the lab. For example, if students had just completed a lesson on solubility, the next lab class would be dedicated to reinforcing the new concepts through the use of either the hands-on or virtual laboratory techniques. Not only does this follow-up provide relevant connections to student learning objectives, it also emphasizes student accountability for their independent learning.

In addition to connectivity between individual and group learning, the materials utilized for virtual lab instruction should be matched to the specific needs of the students. As virtual learning is an emerging construct, the library of available resources for virtual labs is still in early stages of construction (Ma & Nickerson, 2005). The implied pace or the content of existing material may not be appropriate for the target learners. Teachers may wish to consider creating their own digital content rather than use material from third-party sources, such as the American Chemical Society. In doing so, students will be more connected to the material as it originates from a familiar source and is designed to meet their explicit learning goals.

The addition of virtual learning would affect various stakeholders including students, teachers, schools, and curriculum. With the shift from a traditional style of teaching to a more student- focused classroom, including emphasis on inquiry and discovery as the research, teachers would have to be trained on how to best use technology in the classroom. The shift to a student- focused classroom lends itself to an emphasis on laboratory education since the laboratory was the most appropriate place to incorporate inquiry and discovery approaches. Teachers would have to be trained on how to best use technology in the classroom. The curriculum would also have to be tweaked to fit the needs of the students in the online learning.

Also, assessment of lab activities is still severely lacking and this is often due to the continued lack of specific goals. Without specific goals, the assessment of the outcomes of laboratory is impossible. Teachers and administrators lack knowledge and motivation about the uses of these approaches and they lacked the resources to gain an understanding of these new approaches and put them into practice. New technologies in virtual simulations and other tools give teachers access to new possibilities but without knowledge of the specific goals of lab activities and the understanding of the use of these tools, little progress may be achieved by these new technologies.

Limitations of the Study

The limitations of this study are largely attributable to the nature of the participant sample and teacher-researcher involvement. As stated previously, this study employed a convenience sample comprised of the teacher-researcher's own students. A replication of this study should be conducted with participants outside of the teacher-researcher's own student population to confirm that the findings were not impacted by any bias introduced by the researcher. Additionally, the nature of the convenience sample restricted the number of participants in the study, resulting in a relatively small sample size. The reliability of the *r*-values produced within each achievement group should be considered relative to the sample size. It can be argued that there are not enough participants in each sub-group to produce accurate effect size values (Gay et al., 2012). A replication of this study with a larger number of participants may be necessary to confirm initial findings pertaining to effect sizes and levels of achievement.

In conjunction with sampling limitations, there were also no standardized assessments used in this study. For the purpose of the experiment, each assessment needed to be specific and exclusive to the lab content. Questions were similar to that of the New York State Regents

Exam; however, they did not overlap completely. Currently there are no existing standardized tests that would have met the requirements of this study; therefore creating the need to develop a new one.

This is the first experiment of its kind to explore the impact of previous science achievement on performance in the hands-on and virtual lab environments. Although results provide promising evidence to support the implementation of virtual labs for certain populations, additional studies are needed to generalize results beyond the specific contexts of this study and provide larger sample sizes. A reasonable direction for future research would be to conduct similar studies with participants from different geographic locations, including those with more ethnic or economic diversity. It is possible that cultural and/or environmental factors in this specific population impacted the results of this study. A strong majority of participants of this study were white women in their first year of college. Studies that examine the effects of gender may be of future interest. The focus of this study on one specific age group presents a limitation of its findings. Replication of this study with additional age groups is necessary to extend results beyond the 18-20 year-old age range. Also, studies at the elementary and secondary levels would provide more robust literature in this field. The lab content, however, would need to be relevant to the age group.

Finally, only four lab topics were covered in this study. This also limits the findings of the research due to the lack of variety of lab content. Future research should comprise additional laboratory topics in organic chemistry that students have never been exposed to, which will extend the findings of this research. The selection of these virtual labs may or may not represent the latest technological advancement in virtual lab technology. New virtual labs include virtual reality goggles, AR, and other expensive learning tools. Also, new interactive apps on tablets could enhance the molecular modeling learning experience, as not all technology were created equal.

Conclusions

Students are in a unique age of learning as they prepare for future careers in science, engineering and medicine that will rely more on technologies to perform routine tasks, such as building structures and performing surgeries. This may make the virtual lab environment an increasingly more relevant addition as the aspects prepare students for what the future holds.

Although research in this area is progressing, questions remain regarding the impact of virtual labs on performance in the science classroom. As comparative research between the two different laboratory environments continues to reveal the strengths and weaknesses of each; it is safe to say that future research focused on how best to utilize this technological advancement in conjunction with and/or instead of traditional labs, remains unclear.

There have been many studies that compare traditional hands-on and virtual lab learning (Hawkins, 2013; Ma & Nickerson, 2006; Zacharia & Constantinou, 2008); however, there are still no studies that use predictor variables, such as previous science achievement. This was the first study looking at a predictor variable on whether students will succeed in either the virtual or hands-on laboratory settings. A future step would be to investigate the influence of other predictor variables, such as self-efficacy and cognitive load, on the success of students in either laboratory environment.

Furthermore, the findings of this study were in contrast to several found in previous studies regarding hands-on versus virtual achievement (Darrah et al., 2014; Ma & Nickerson, 2006; Tatli & Ayas, 2013). One potential explanation was that the age and level of study might have contributed to the disparity of findings; therefore, future research should investigate how the effects of virtual labs differ between students of various age groups.

The data revealed that students did not perform significantly better in either of the lab experimental designs (hands-on or virtual), which suggests that the intervention was comparably effective for all students. The data also showed that high-achieving students outperformed low-achieving students on virtual lab experimentation. This finding suggests that low-achieving students may fall behind academically if only the virtual laboratory environments are utilized. Since there were no covariates, the t-test and MANOVA analyses could evaluate whether the means of the dependent variables, achievement on the hands-on or virtual labs, were equal across levels of the categorical independent variable. The lack of covariates made this a powerful study, as only the treatment could explain the analysis of variance.

Although there was a smaller sample size, this study showed a profound advantage for high-achieving students on virtual lab experiments. Low-achieving students learned the lab material, however, the effect was not as profound as their high-achieving counterparts. Findings of this study suggest that the use of virtual labs does not harm science achievement and may conserve resources, but may expand the gap between high- and low-achieving students in the science laboratory.

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Appendix A

Research Consent Form

Introduction: This research aims to compare traditional hands-on laboratory experiments with virtual laboratory experiments.

Study Procedures: During this study, you will be asked to participate in several tests/quizzes. The tests/quizzes will not affect your overall chemistry grade in this course. Your test scores in the course, as well as your high school chemistry grade, will be looked at for the sole purpose of this study.

- Pre tests, along with your high school chemistry grade, will be used as a basis for your current chemistry knowledge.
- Your test scores after completing labs will be used to assess how you do in both the hands-on and virtual laboratory environments.

Risks: There are no risks in this study including physical, psychological, social or legal risks.

Benefits: The benefits of participation include your reflection on the experiences in the chemistry course. Your scores and perspectives could help improve the chemistry course for future students.

Alternative to Participation: If you decide not to participant in the study, your performance in the chemistry course of interest will in no way be affected. You are free to withdraw from the study at any time without penalty.

Confidentiality: If you choose to be a participant in this study, all information will be kept strictly confidential by assigning a pseudonym (different name) to you, the participant. If any publications are made from this study, neither you nor identifying information will be used.

Questions: All questions will be answered to your satisfaction before you give consent for your participation within this study.

Voluntary Consent: You are free to withdraw your consent or to discontinue participation within the study at any time without penalty.

I voluntarily give my consent to participant in this study. I understand that I will be given a copy of this consent form for my records.

___________________________ ___________________________

Participant's Name Date

___________________________ ___________________________

Participant's Signature Researcher's Signature

Appendix B

Hands-on Laboratory Procedure and Data

Lab #1 – Density – Hands-On Lab

1- Density: Weigh an empty 10.0 ml graduated cylinder on the electronic balance. Now fill the cylinder with water to the 10.0 ml mark. Weigh the cylinder and water. What is the density of water? (Remember to always include units)

(a) Weight of cylinder

(b) Weight of water and cylinder

(c) Weight (mass) of water: = (b-a)

(d) What is the calculated density of water: D=M/V

(e) What is the actual density of water? Check the chemistry manual in the lab room

(f) What is the percent error (1-(calculated/actual)) x 100?

2 - Weigh an empty 10.0 ml graduated cylinder on the electronic balance. Rinse the 10.0 ml graduated cylinder with ethanol. Then fill the cylinder to the 10 ml mark with ethanol. Weigh the cylinder and ethanol. What is the density of ethanol?

(a) Weight of cylinder

(b) Weight of ethanol and cylinder

(c) Weight (mass) of ethanol: = (b-a)

(d) What is the calculated density of ethanol: D=M/V

(e) What is the actual density of ethanol? Check the chemistry manual in the lab room

(f) What is the percent error (1-(calculated/actual)) x 100?

3 – Fill a 100.0 ml graduated cylinder to the 50.0 ml mark with water. Then weigh a metal block on the electronic balance. **Carefully slide the metal sinker into the cylinder.** Do not drop the block into the cylinder. How much water does it displace? Remember fifty equates to zero as the starting point. Calculate the density of the sinker.

(a) Weight (mass) of metal sinker

(b) Volume (the amount of water displaced by the sinker)

(c) What is the calculated density of the metal sinker: D=M/V (a/b)

(d) What is the actual density of the metal?

(e) What is the percent error (1-(calculated/actual)) x 100?

4 – Measure the same metal block (L x W x H) to the nearest centimeter. Then weigh the metal block on electronic balance. Calculate the density of the block.

(a) Weight (mass) of metal block

(b) Cubic Volume of metal block

(c) What is the calculated density of the metal block? D=M/V (a/b)

(d) What is the actual density of the metal? Check the chemistry manual in the lab room

(e) What is the percent error (1-(calculated/actual)) x 100?

Appendix C

Lab #1 Post-Test Assessment

1) Which one of the following substances will float in gasoline, which has a density of 0.74 g/mL? The density of each substance is shown in parentheses.
A) table salt (D = 2.16 g/mL)
B) balsa wood (D = 0.16 g/mL)
C) sugar (D = 1.59 g/mL)
D) aluminum (D = 2.70 g/mL)
E) mercury (D = 13.6 g/mL)

2) What is the mass of 53 mL of ethanol, which has a density of 0.79 g/mL?
A) 67.1 g
B) 41.9 g
C) 42 g
D) 67 g
E) 53 g

3) A liquid has a volume of 34.6 mL and a mass of 46.0 g. What is the density of the liquid?
A) 1.00 g/mL
B) 1.33 g/mL
C) 0.752 g/mL
D) 133.0 g/mL
E) 0.663 g/mL

4) The ratio of the mass of a substance to its volume is its ________.
A) specific gravity
B) density
C) buoyancy
D) weight
E) conversion factor

5) A nugget of gold with a mass of 521.0 g is added to 50.0 mL of water. The water level rises to a volume of 77.0 mL. What is the density of the gold?
A) 10.4 g/mL
B) 6.77 g/mL
C) 1.00 g/mL
D) 0.0518 g/mL
E) 19.3 g/mL

6) In order to find out the volume of an irregular object, what method is used?

A) Triple Beam Balance
B) Volume Manipulation
C) Multiplication
D) Volume Displacement

7) Density is an example of a(n) ___________ property.

A) Intrinsic
B) Extrinsic
C) Nontrinsic
D) Exact
E) Inexact

8) Density is defined as ________________.

A) Volume per weight of a substance
B) Weight per volume of a substance
C) Volume per mass of a substance
D) Mass per volume of a substance

9) There are two pieces of copper. Piece A is twice the mass and volume of piece B. How can we compare the two densities?

A) The density of A will be double the value of B
B) The density of B will be double the value of A
C) The density of A will be half the value of B
D) The density of B will be half the value of A
E) The densities of A and B will be the same

10) The most precise way to measure out 9.0 mL of liquid would be to use which instrument?

A) 10.0 mL beaker
B) 50.0 mL beaker
C) 100.0 mL beaker
D) 10.0 mL graduated cylinder
E) 50.0 mL graduated cylinder

Appendix D

Virtual Laboratory #1 Procedure

Lab #1 – Density – Virtual Lab

Materials: Computer, CUNY Brooklyn Simulation and Glencoe Online Learning Center Simulation

Density of Various Minerals

1. Copy and paste the following link into a web browser:

http://academic.brooklyn.cuny.edu/geology/leveson/core/graphics/density/densityex_1.html

Read the instructions on the left hand side of the page to aid in the lab and how to use the density simulator.

1. After you have read these instructions (1 through 10), you will go to the Virtual Density Testing Lab. There you will see the Density Evaluation Table. A non-working *sketch* (not the real thing) of the Table is shown on the right. The mineral numbers on this sketch are not the same as on the real table!
2. HOW THE TABLE WORKS: The Table is designed to allow you to determine the densities of minerals. In the central section of the Table is a box in which instructions will appear as you perform the investigation.
3. On the left of the Table is a list of minerals to be tested. The minerals are identified by numbers. On the real Table, when you click on one of the minerals (other than 'None'), two things will happen:
    1. A picture of the mineral will appear in the central section of the Table at the top.
    2. A picture of a graduated cylinder (cylinder 1) with the mineral specimen suspended above the water level will appear on the left.
4. If one of the minerals you have been assigned appears on the list, click on the button next to it.
5. On a piece of paper, record the number of the mineral and the level of the water in cylinder 1.
6. Next, press the 'Immerse the Mineral' bar. A picture of the graduated cylinder with the mineral immersed in the water will appear on the right. On the piece of paper, record the new level of the water.
7. The volume of the mineral is equal to the difference between the water levels in cylinders 1 and 2. Record the volume on the piece of paper.
8. Press the 'Weigh the Mineral' bar. A picture of the scales of a triple beam balance will appear with the weights set to counterbalance the mineral. Determine the weight and compute the density of the mineral: Density = Weight/Volume. Since this is a virtual lab, all density values are the actual density values and so percent error will not have to be determined for each of the following minerals.
9. Record the number of the mineral and its density on your data sheet.

Density of Various Objects

1. Copy and paste the following link into a web browser:

http://glencoe.mheducation.com/sites/0078741858/student_view0/unit1/chapter3/virtual_labs.html#

2. Click and drag the piece of wood onto the electric scale to measure the mass of the object. Record this mass in your table.

3. Click and drag the piece of wood into the cylinder of water and see how much volume is displaced. Record this volume in your table.

4. Form a hypothesis and choose whether you believe the object will sink or float in water (D = 1.00 g/mL).

5. Calculate the density from the values you recorded (D = M / V).

6. Click and drag the piece of wood back onto the top shelf and complete steps 2-5 with the other 8 objects in the lab.

7. Since this is a virtual lab, all density values are the actual density values and so percent error will not have to be determined for each of the following objects. Given the situations at the end of your lab, calculate the percent error of an unknown sample of copper and aluminum. (% Error = (1 – (calculated / actual)) x 100)

Appendix E

Virtual Laboratory #1 Data Sheet

Lab #1 – Density – Virtual Lab Data Sheet

Materials: Computer, CUNY Brooklyn Simulation and Glencoe Online Learning Center Simulation

Density of Various Minerals

Mineral Number	Volume Before Adding Mineral	Volume After Adding Mineral	Volume of Mineral	Mass of Mineral	Density of Mineral (D = M / V)

Density of Various Objects

Object	Mass of Mineral	Volume of Mineral	Density of Mineral (D = M / V)

Percent Error Calculations

Since this is a virtual lab, all density values are the actual density values and so percent error will not have to be determined for each of the following minerals.

Given the following situations, calculate the percent error of a sample of copper and aluminum. (% Error = (1 – (calculated / actual)) x 100)

1. A student measures the mass of a piece of copper to be 28.10 g. The student then places the piece of copper into a graduated cylinder filled to 50.0 mL of water and the water rises to 54.8 mL.

   (a) Calculate the density of the piece of copper.
   (b) If the actual density of copper is 8.96 g/mL, what is the percent error?

2. A student measures the mass of a piece of copper to be 15.75 g. The student then places the piece of aluminum into a graduated cylinder filled to 50.0 mL of water and the water rises to 55.0 mL.

   (a) Calculate the density of the piece of copper.
   (b) If the actual density of copper is 2.70 g/mL, what is the percent error?

Appendix F

Hands-on Laboratory #2 Procedure

Lab #2 – Acids and Bases– Hands-On Lab

1. pH of Acids:

Place 5 drops of a 25% solution of:
hydrochloric acid (HCl)
nitric acid (HNO3)
sulfuric acid (H2SO4)
acetic acid (HC2H3O2)
boric acid (H3BO3)

into separate depressions of a dropping plate. Test each acid with a strip of universal indicator paper. Record the pH

2. pH of Bases:

Place 5 drops of a 25% solution of:
sodium hydroxide (NaOH)
potassium hydroxide (KOH)
calcium hydroxide ($Ca(OH_2)$)
sodium bicarbonate ($NaHCO_3$)

into separate depressions of a dropping plate. Test each acid with a strip of universal indicator paper. Record the pH

3. Indicators:

(a) place several drops of 25% HCl solution into a depression of a dropping plate.

(b) in another depression place several drops of 25% NaOH solution.

Add a drop of bromothymol blue indicator dye to the HCl and also add a drop of bromothymol blue to the NaOH. Note in the chart the color changes.

Follow the same procedure using:

Phenolphthalein
Methyl red
Bromocresol purple
Methyl orange

Thymolphthalein
Methyl violet

Record in the chart all color changes with different indicators.

4. Buffer Systems:

(a) Prepare two test tubes for each of the following solutions. Mark the tubes so you can remember their contents.

Solution A: 40 drops of 0.1 M sodium acetate solution ($NaC_2H_3O_2$) plus 40 drops of 0.1 M acetic acid solution ($HC_2H_3O_2$)

(b) Use universal pH paper (range 1 to 14) to measure the pH of each solution. Record this initial pH value.

(c) Also measure and record the pH of a sample of distilled water

(d) Add 20 drops of 0.05 M hydrochloric acid (HCl) to one sample of Solution A and to a 30 drops sample of distilled water. Mix well, measure, and record the resulting pH of each solution.

(e) Repeat Step D, using the other Solution A sample and a fresh sample of distilled water, but add 20 drops of 0.05 M sodium hydroxide solution (NaOH) instead of HCl.

INDICATOR	COLOR CHANGE	pH AT COLOR CHANGE
Methyl violet	green to violet	0.0 - ≥ 1.6
Methyl orange	red to yellow	≤3.2 - ≥ 4.4
Methyl red	red to yellow	≤ 4.8 - ≥ 6.0
Bromocresol purple	yellow to purple	≤ 5.2 - ≥ 6.8
Bromothymol blue	yellow to blue	≤ 6.0 - ≥ 7.6
Phenolphthalein	colorless to pink	≤ 8.2 - ≥ 10
Thymolphthalein	colorless to blue	≤ 9.4 - ≥ 10.6

Appendix G

Hands-on Laboratory #2 Data Sheet

Lab #2 – Acids and Bases– Hands-On Lab Data Sheet

1- Acids: Record the pH of the following acids

(a) HCl

(b) HNO_3

(c) H_2SO_4

(d) $HC_2H_3O_2$

(e) H_3BO_3

Which of the following acids are strong? Which are weak?

How do you know?

2- Bases: Record the pH of the following acids

(a) $NaOH$

(b) KOH

(c) $Ca(OH)_2$

(d) $NaHCO_3$

Which of the following bases are weak?

Explain:

Appendix H

Lab #2 Post-Test Assessment

1) Which of the following solutions is NOT acidic?
A) vinegar, pH 2.8
B) shampoo, pH 5.7
C) honey, pH 3.9
D) seawater, pH 8.5

2) Identify the conjugate base in the following equation.

$$HCl(aq) + Na_2CO_3(aq) \longrightarrow Na^+(aq) + Cl^-(aq) + HCO_3^-(aq)$$

A) Na^+
B) HCO_3^-
C) Cl^-
D) HCl

3) Which of the following can be used to measure pH of solutions?

A) A Buffer system
B) Universal Indicator Paper
C) Acetic acid solution
D) pH cannot be measured

4) The pH values of acids will always be ____________.

A) Exactly 7.0
B) Greater than 7.0
C) Less than 7.0
D) Neutralized

5. The pH values of strong bases will always be ________ weak bases.

A) Greater than
B) Less than
C) The same as
D) Identical to

6) According to the Arrhenius concept, if HNO_3 were dissolved in water, it would act as ________.

A) a base
B) an acid
C) a source of hydroxide ions
D) a source of H^- ions
E) a proton acceptor

7) Which of the following statements correctly describes the hydronium-hydroxide balance in the given solution?

A) In acids, $[OH^-]$ is greater than $[H_3O^+]$.
B) In bases, $[OH^-] = [H_3O^+]$.
C) In neutral solutions, $[H_3O^+] = [H_2O]$.
D) In bases, $[OH^-]$ is greater than $[H_3O^+]$.
E) In bases, $[OH^-]$ is less than $[H_3O^+]$.

8) When an acid reacts with a metal like Al, the products are ________.

A) water and a base
B) water and a salt
C) water and carbon dioxide
D) a salt and carbon dioxide
E) a salt and hydrogen

9) The neutralization reaction between $Al(OH)_3$ and HNO_3 produces the salt with the formula ________.

A) H_2O
B) $AlNO_3$
C) AlH_2
D) $Al(NO_3)_3$
E) NO_3OH

10) The function of a buffer is to ________.

A) change color at the end point of a titration
B) maintain the pH of a solution
C) be a strong base
D) maintain a neutral pH
E) act as a strong acid

Appendix I

Virtual Laboratory #2 Procedure

Lab #2 – Acids and Bases– Virtual Lab

Materials: Computer and Phet Interactive Simulation

All of the chemicals in the field of inorganic chemistry or the chemistry of the non-carbon compounds, consist of only three kinds – acids, bases, and salts (There are many different kinds of organic or carbon chemicals).

Acids:	H^+ donor
Bases:	H^+ acceptor or OH^- donor
Salts:	formed from the reaction of an acid and base (Neutralization)

pH measures the acidity of acids, bases, and salts. It is an arbitrary scale from 0-14, where 7 is neutral, 0-<7 is acidic, and >7-14 basic.

pH of Strong/Weak Acids and Bases

1. Copy and paste the following link into a web browser:

https://phet.colorado.edu/sims/html/acid-base-solutions/latest/acid-base-solutions_en.html

and click on introduction. In the "solution" box on the right, click on water and observe the solution. Note the red molecules as acids (H_3O^+) and the blue molecules as bases (OH^-). To test the pH of water, take the pH meter at the top right and drag it into the solution. Note the pH.

Under the "tools" box on the bottom right, click on the middle pH strips icon and dip the pH strip into the solution. Note the color and corresponding pH value.

Lastly, under the "tools" box on the bottom right, click on the right lightbulb to check to see if the solution is an electrolyte. Dip the positive and negative ends of the battery into the solution and note if the solution is an electrolyte or not.

2. Now follow the same procedure with a weak acid. Click on "weak acid" in the top right box. Note the red molecules as acids (H_3O^+) and the blue molecules as bases (OH^-). Notice how this is different than the water.

To test the pH of the weak acid, take the pH meter at the top right and drag it into the solution. Record the pH value.

Under the "tools" box on the bottom right, click on the middle pH strips icon and dip the pH strip into the solution. Note the color and corresponding pH value.

Lastly, under the "tools" box on the bottom right, click on the right lightbulb to check to see if the solution is an electrolyte. Dip the positive and negative ends of the battery into the solution and note if the solution is an electrolyte or not.

3. Complete the same procedure as number 2, but now with the strong acid. Make sure to note the differences in molecules between the two solutions. Record all pH values and colors.

4. Complete the same procedure as number 2, but now with the weak base. Make sure to note the differences in molecules between the two solutions. Record all pH values and colors.

5. Complete the same procedure as number 2, but now with the strong base. Make sure to note the differences in molecules between the two solutions. Record all pH values and colors.

Indicators and pH

1. Copy and paste the following link into a web browser:

http://www.harpercollege.edu/tm-ps/chm/100/dgodambe/thedisk/ph/ph.htm

and click on "background." This section will explain acids and bases in regards to molarity and concentrations hydronium (H_3O^+) and hydroxide (OH^-). Towards the bottom click on "pH" and read through concentrations of hydronium (H_3O^+) and hydroxide (OH^-) and how they relate to pH. Lastly click on "using acid-base indicators," to learn more about indicators that will be used in the lab. After you have read the background information click on the bottom link "experiment" to get started.

Part 1

Click on "Part 1: Determining Indicator Color Change Regions" and click on each of the 9 indicators to see the color change at different pH values. Make sure to record both the pH of the change (it should be 2 - 4 pH units) and the color before, during and after each of the changes. Remember that some indicators may have more than one color change region. Each of the links below takes you to a page that has 13 test tubes containing buffers with pH's from 1 to 13. To each 2 - 4 drops of referenced indicator has been added.

Create a table of each of the 9 indicators and their colors at the differing pH values.

Part 2

Click on Continue on and perform "part 2." Determine the approximate pH of each of the solutions you have been assigned (either A-D, E-H or I-K).

Click on the test tube (test tubes look like the picture to the left) to see the results of mixing the indicated solutions. The picture that appears shows three test tubes containing the solution and indicators in the order that they are listed on the grid. After viewing the picture, record your observations and click the back button of your browser to return to the grid.

Part 3

Click on Continue on and perform "part 3." Identify the approximate pH of the solutions you have been assigned.

Each of the links below takes you to a page that shows you a piece a pH paper which has been wetted with the indicated solution and the pH chart that goes with the paper. Record your observations. Note if there was a difference between the indicator pH range and the pH paper.

Buffers and pH

Copy and paste the following link into a web browser:

http://www.harpercollege.edu/tm-ps/chm/100/dgodambe/thedisk/bloodbuf/zperform.htm

and click on "perform the experiment." This part of the experiment is divided into nine steps. At each step you will be shown a picture taken while that step was performed. You will also be able to read the pH and to see a close-up picture of the beaker taken after the step has been completed. For each step you should record your observations. Your observations might include a color change, precipitate formation, evolution of gas, or some similar result. For example you might record, "small bubbles were formed". Your observations should not include an explanation of what you think occurred. For example, you should not say "carbon dioxide gas was formed".

1. To start, 100 ml of water was placed in a 250 ml beaker. The electrode was lowered into the solution and the pH was measured. Click on "read pH," and record the pH of the solution. Click on "continue to next step," on the bottom left of the page.

2. In this step, 2.5 g of $NaHCO_3$ was dissolved into the distilled water and stirred at a moderate rate. Click on "read pH," and record the pH of the solution. Click on "continue to next step," on the bottom left of the page.

3. In the third step, 30 ml of 0.1 M HCl was added to the solution. To make the buffer, we need to have significant amounts of both HCO_3^- and H_2CO_3 in solution. Adding HCl converts some of the bicarbonate into carbonic acid. Click on "read pH," and record the pH of the solution. Also click on "view close-up" to see a picture of the solution taken after several minutes passed. Click on "continue to next step," on the bottom left of the page.

4. In the fourth step, 10 ml of 0.85% lactic acid were added. During normal metabolism the body produces small amounts of lactic acid. This step simulates the formation of a large amount of lactic acid. Click on "read pH," and record the pH of the solution. Also click on "view close-up"

to see a picture of the solution taken after several minutes passed. Click on “continue to next step,” on the bottom left of the page.

5. When the body senses that the blood pH is low, the body attempts to compensate (increase pH) by increasing the rate of respiration so that more CO_2 is expired. This action can be simulated by stirring the solution vigorously. Notice that CO_2 bubbles are leaving the solution. Click on “read pH,” and record the pH of the solution. Click on “continue to next step,” on the bottom left of the page.

6. In a critical clinical situation of low pH, sodium bicarbonate may be given intravenously after careful calculation of the appropriate amount necessary. We will simulate this by adding some solid sodium bicarbonate. Click on “read pH,” and record the pH of the solution. Click on “continue to next step,” on the bottom left of the page.

7. If too much bicarbonate is administered, the pH may be raised too high. Additional sodium bicarbonate is added to simulate this mistake. Click on “read pH,” and record the pH of the solution. Click on “continue to next step,” on the bottom left of the page.

8. When the body senses a high blood pH, it reduces breathing to limit the exhalation of CO_2. We can simulate this effect by adding dry ice (solid CO_2) to the beaker. Click on “read pH,” and record the pH of the solution. Click on “continue to next step,” on the bottom left of the page.

9. In extreme cases of high pH, a dilute acid may be injected directly into the blood. We can simulate this by adding solid NH_4Cl to the beaker. Click on “read pH,” and record the pH of the solution. Click on “continue to next step,” on the bottom left of the page.

Appendix J

Hands-On Laboratory #3 Procedure

Lab #3 – Organic Models

Materials: Molecular Model Kits

There are more compounds of the element carbon than those of all other elements in the periodic table. The field of organic chemistry is extremely extensive.

Organic compounds are formed from electron-sharing bonds (represented by the sticks or spiral wires in the molecular model set) rather than by a give and take of electrons, as in inorganic compounds.

These bonds can form single bond, double bond, triple bond, or cyclic compounds.

Carbon compounds can have different arrangements. These are known as isomers. Isomers are sets of compounds having the same numbers and kinds of atoms with different arrangements.

The body is sensitive to structure, and will utilize only certain isomers. If these needed structures are not available, it will convert other molecules to them in the presence of the category of enzymes known as isomerases.

1. Hydrocarbons – First three in the alkane series:

Sketch diagrams of your models.

2. Structural Positional Isomers

(a) Now construct the 4 carbon hydrocarbon, butane (C_4H_{10}).

(b) Try to rearrange the chain by taking a carbon from the end of the chain and attaching it to the middle carbon. (See that all carbons have four bonds).

This rearrangement has resulted in a new compound, *isobutane*

3 <u>Optical isomers</u>

Another type of isomerism is optical or mirror image. This can occur when there is a chiral carbon, or one having four different groups attached to the four bonds of carbon.

Make mirror images of a theoretical carbon compound having four different colored balls attached to a black ball representing carbon. (Bond four different colored balls to carbon (C). Make the reverse structure)

The test of mirror images is that they are not superimposable. To see if you really made them, try to put one molecule on top of the other. If the color of the balls of one molecule is the same as the ones underneath, it is not an isomer, but the identical molecule.

4 Functional Isomers

Sometimes by rearranging the atoms of a molecule, the functionality can change; for instance, an alcohol can become an ether.

(a) Set up a molecule of ethanol (CH_3CH_2OH).

(b) By retaining the same number and kinds of atoms in the molecule, convert this to dimethyl ether (CH_3OCH_3).

5 Cis-Trans Isomers

These are possible because the rotation around a double bond is restricted.

(a) Construct an ethene (ethylene molecule (CH_2CH_2). (Use two spiral wires for the double bond).

(b) Remove one hydrogen (from each carbon atom) on the same side of the double bond. Replace the hydrogens with chlorine atoms (green balls)
(c) Construct an ethene (ethylene) molecule. (Use two spiral wires for the double bond)
(d) Remove one hydrogen (from each carbon) on opposite sides of the plane of the double bond. Replace with chlorine atoms. Draw.

6 Cyclic Compounds

Carbon can also form cyclic compounds.

(a) Benzene: Using the wires and sticks from the model sets as bonds, (two wires represent a double bond), make the benzene or aromatic ring (C_6H_6). Draw it.

(b) Cyclopropane: Since cyclopropane is such a strained structure, wires will have to be used for single bonds between the carbon atoms $(CH_2)_3$. Sketch this

Appendix K

Hands-on and Virtual Labs #3 Data Sheet

Lab #3 – Organic Models

OBSERVATIONS

1. Sketch a model of:	Condensed Structural Formula:
(a) Methane	(1a)
(b) Ethane	(1b)
(c) Propane	(1c)

(d) Are any other arrangement of atoms in these compounds possible? Explain.

2. Draw/Sketch: Condensed Structural Formula:

(a) Butane (2a)

(b) Isobutane (2b)

3. Construct the two mirror image isomers:

4. Diagram

(a) Ethanol molecule: (4a)

(b) Dimethyl Ether molecule: (4b)

5. Construct Models of:

(a) Ethene

(5a) What type of bonding to the C's in this molecule have?

(b) cis isomer

(5b) Name this isomer.

(c) trans isomer

(5c) Name this isomer.

6. Draw/Sketch:

(a) Benzene Ring:

(b) Cyclopropane

Appendix L

Lab #3 Post-Test Assessment

1) Isomers are molecules that share the same formula and have ________.

A) a different shape to the molecule
B) the same arrangement of atoms within the molecule
C) a different arrangement of atoms within the molecule
D) identical boiling points
E) the same shape in each molecule

2) In the three-dimensional structure of methane, CH_4, the hydrogen atoms attached to a carbon atom are aligned ________.

A) in a straight line
B) at the corners of a square
C) at the corners of a tetrahedron
D) at the corners of a rectangle
E) at the corners of a cube

3) A hydrocarbon contains only the elements ________.

A) hydrogen and oxygen
B) carbon and oxygen
C) carbon and hydrogen
D) carbon, hydrogen, and oxygen
E) carbon, hydrogen, and nitrogen

4) Carbon atoms always have how many covalent bonds?

A) one
B) two
C) three
D) four
E) five

5) The simplest cycloalkane has ________.

A) one carbon atom
B) two carbon atoms
C) three carbon atoms
D) four carbon atoms
E) five carbon atoms

6) Compounds that have the same molecular formula but different arrangements of atoms are called ________.

A) isomers
B) isotopes
C) indicators
D) isozymes
E) isometrics

7) Some alkenes have geometric (cis-trans) isomers because ________.

A) the carbon atoms in the double bond cannot rotate
B) each of the carbon atoms in the double bond has four different groups attached to it
C) one of the carbon atoms in the double bond has two identical groups attached to it
D) the carbon atoms in the double bond are free to rotate
E) all of the carbon atoms in the compound are rigid and cannot rotate

8) Compounds that have the same molecular formula but different arrangements of atoms are called ________.

A) isomers
B) isotopes
C) indicators
D) isozymes
E) isometrics

9) Which of the following substances has the same molecular and structural formulae, but different spatial arrangements?

A) structural positional isomers
B) optical isomers
C) functional isomers
D) cis-trans isomers
E) isotopes

10) Which of the following substances has the same molecular, but different chemical properties and behaviors?

A) structural positional isomers
B) optical isomers
C) functional isomers
D) cis-trans isomers
E) isotopes

Appendix M

Virtual Laboratory #3 Procedure

Lab #3 – Organic Models – Virtual Lab

Materials: Computer and Phet

There are more compounds of the element carbon than those of all other elements in the periodic table. The field of organic chemistry is extremely extensive.

Organic compounds are formed from electron-sharing bonds (represented by the sticks or spiral wires in the molecular model set) rather than by a give and take of electrons, as in inorganic compounds.

These bonds can form single bond, double bond, triple bond, or cyclic compounds.

Carbon compounds can have different arrangements. These are known as isomers. Isomers are sets of compounds having the same numbers and kinds of atoms with different arrangements.

The body is sensitive to structure, and will utilize only certain isomers. If these needed structures are not available, it will convert other molecules to them in the presence of the category of enzymes known as isomerases.

1. Copy and paste the following link into a web browser:

https://phet.colorado.edu/en/simulation/build-a-molecule

This is the Build a Molecule Phet Interactive Simulations Application. Open up the program and click on the top right of the program where it says "Larger Molecules."

Begin virtually constructing the hydrocarbons – the first three in the alkane series. Place carbon atoms next to each other and make sure to place the correct number of hydrogens on each carbon. After completing the molecule, click on the green "3D" button and on the bottom click "ball and stick" model. Screen shot and sketch diagrams of each of the first three alkanes.

2. Structural Positional Isomers

(a) Now construct the 4 carbon hydrocarbon, butane (C_4H_{10}).

(b) Try to rearrange the chain by taking a carbon from the end of the chain and attaching it to the middle carbon. (See that all carbons have four bonds.) This rearrangement has resulted in a new compound, isobutene. Screen shot and sketch diagrams of each of the structures on your data sheet.

3. Optical Isomers

Another type of isomerism is optical or mirror image. This can occur when there is a chiral carbon, or one having four different groups attached to the four bonds of carbon.

Make mirror images of a theoretical carbon compound by placing a hydrogen, oxygen, nitrogen and another carbon on a carbon atom. Now construct the reverse structure. Screen shot and sketch diagrams of each of the structures.

4. Functional Isomers

Sometimes by rearranging the atoms of a molecule, the functionality can change; for instance, an alcohol can become an ether.

(a) Set up a molecule of ethanol (CH_3CH_2OH).
(b) By retaining the same number and kind of atoms in the molecule (leave them on the screen), convert this to dimethyl ether (CH_3OCH_3). Screen shot and sketch diagrams of each of the structures.

5. Cis-Trans Isomers

These are possible because the rotation around the carbon-carbon double bond is restricted.

(a) Construct an ethene (ethylene molecule (CH_2CH_2). Make sure to add the correct number of hydrogens, and the computer simulation will make the correct number of double bonds.
(b) Remove one hydrogen (from each carbon atom) on the same side of the double bond. Replace the hydrogens with chlorine atoms.
(c) Click on the green “3D” button and click “ball and stick” on the bottom right. Notice the chlorine atoms are on opposite sides of the double bond. This isomer is more stable. Screen shot and sketch diagrams of each of the structures.
(d) Even though the computer simulation won’t let you create the cis isomer, draw the isomer on your data sheet.

Appendix N

Hands-on Laboratory #4 Procedure

Lab #4 – Solubility and Conductivity – Hands-on Lab

Organic chemicals are compounds of carbon. They are much more numerous than inorganic compounds, or non-carbon compounds. Organic and inorganic chemicals will be contrasted in this experiment.

Salicylic acid (C_6H_4 (OH)(COOH) and methanol typify organic chemicals. Table salt, sodium chloride(NaC1) and water represent inorganic chemicals.

1. **Solubility in an Organic Solvent**

(a) Dissolve a small quantity of salicylic acid in a test tube half-filled with methanol (CH3OH.) Is it soluble?
(b) Repeat this procedure using sodium chloride (NaCl), in methanol, (CH3OH).

2. **Solubility in an Inorganic Solvent** [(Let water represent inorganic solvent)]

(a) Dissolve a small quantity of sodium chloride (NaCl), in a test tube of water.
(b) Repeat this procedure using salicylic acid and water.

3. **Conductivity Demonstration:**

Organic compounds compared with inorganic compounds

Using the conductivity apparatus, observe the differences in the electrical conduction of:

(a) distilled water
(b) NaC1 in water
(c) salicylic acid in methanol

Appendix O

Hands-on Laboratory #4 Data Sheet

Lab #4 – Solubility and Conductivity

Observations:

Solubility notation of chemical handbook:

s = soluble
ss = slightly soluble
i = insoluble

1. Solubility in an Organic Solvent

a) Salicylic acid in methanol

b) NaCl in methanol

c) In which type of solvents (organic or inorganic) do organic solutes dissolve?

2. Solubility in an Inorganic Solvent

a) NaCl in water

b) Salicylic acid in water

c) In which type of solvents (organic or inorganic) do inorganic solutes dissolve?

3. Conductivity

a) Does distilled water conduct?

b) Is NaCl an electrolyte? (A substance whose water solution conducts electricity.)

c) Is salicylic acid an electrolyte or a non-electrolyte?

Appendix P

Lab #4 Post-Test Assessment

1) In a solution, the solvent ________.

A) is a liquid.
B) can be a liquid or gas.
C) can be a solid, liquid, or gas.
D) is never a solid.
E) is the substance present in the smallest concentration.

2) Vinegar is a solution that contains approximately 4 g of acetic acid in 100 mL of water. Identify the solute and solvent in this solution of vinegar.

A) Vinegar is the solute; water is the solvent.
B) Water is the solute; vinegar is the solvent.
C) Acetic acid is the solute; water is the solvent.
D) Water is the solute; vinegar is the solvent.

3) Oil does not dissolve in water because ________.

A) oil is polar
B) oil is nonpolar
C) water is nonpolar
D) water is saturated
E) oil is hydrated

4) Water is a polar solvent and hexane (C_6H_{14}) is a nonpolar solvent. Which of the following correctly describes the solubility of the solute in the given solvent?

A) Mineral oil, soluble in water
B) $CaCl_2$, soluble in hexane
C) $NaHCO_3$, soluble in water
D) CCl_4, soluble in water
E) Octane, soluble in water

5) If solid NaCl (inorganic) was placed in a methanol (organic) solution, the NaCl would ________.

A) dissolve completely
B) dissolve slightly
C) not dissolve at all

6) Organic solutes are soluble in ________ solvents.

A) inorganic
B) organic
C) ionic
D) nonpolar
E) polar

7) A substance that carries an electric current when dissolved in water is called a(n) ________.

A) weak acid
B) strong acid
C) weak base
D) strong base
E) electrolyte

8) A substance that produces only a small number of ions in solution is known as a ________ electrolyte.

A) strong
B) weak
C) semi
D) non

9) When NH_4Cl (inorganic) is added to water (inorganic), the salt will be ________.

A) soluble
B) insoluble
C) independent
D) a non electrolyte

10) Red litmus paper will turn blue in the presence of _________.

A) an acid
B) a base
C) NaCl (a salt)
D) any electrolyte
E) any nonelectrolyte

Appendix Q

Virtual Laboratory #4 Procedure

Lab D – Solubility and Conductivity – Virtual Lab

Materials: Computer, Phet Interactive Simulations and YouTube

Like Dissolves Like

1. Open up the following YouTube video link:

https://www.youtube.com/watch?v=7OuJ6ierB9s

After viewing the video on polar and nonpolar solutes and solvents, answer a few short answer questions and fill in the table given.

Solubility

2. Copy and paste the following link into a web browser:

https://phet.colorado.edu/en/simulation/legacy/sugar-and-salt-solutions

Make sure the “micro” tab is clicked on the top left of the simulation.

(a) Click and drag saltshaker downward to add sodium chloride (NaCl) to the water. Notice on the top right the concentrations of Na^+ and Cl^- increase as you add more salt. Also note the way the Na^+ and Cl^- move in solution.

(b) Click “water” tab on the top left of the simulation and note the waters activity. Then click and drag the salt (sodium chloride) into the water and observe the ions in water.

(c) Repeat steps (a) and (b) but this time use sugar (sucrose – $C_{12}H_{22}O_{12}$). Note any differences between salt and sugar.

Conductivity

3. Make sure the “macro” tab is clicked on the top left of the simulation.

(a) Click and drag saltshaker downward to add sodium chloride (NaCl) to the water. Notice on the top right the concentration of salt in the chart increases as you add more.

(b) Drag the conductivity meter on the right side of the simulation into the water and see if the solution conducts electricity.

(c) Click “reset all” on the bottom right of the simulation, change the solute the “sugar” and complete parts (a) and (b) and note any differences in conductivity between salt and sugar.

Appendix R

Virtual Laboratory #4 Data Sheet

Lab D – Solublity and Conductivity – Virtual Lab Data Sheet

Materials: Computer, Phet Interactive Simulations and YouTube

Like Dissolves Like

1. (a) Why did the nonpolar solid dissolve in the carbon tetrachloride (CCl_4)?

   (b) Why doesn't the water mix with the carbon tetrachloride (CCl_4)?

   (c) Why does the hexane (C_6H_{14}) end up mixing with the carbon tetrachloride (CCl_4)?

   (d) Fill in the following chart. Decide whether the solute will be soluble or insoluble in the following solvents.

	Solvent		
Solute		Water (H_2O)	Carbon Tetrachloride (CCl_4)
	Sodium Chloride (NaCl)		
	Hexane (C_6H_{14})		

2. (a) How does the salt (NaCl) behave in water?

   (b) What happens to the ions of salt (NaCl) when placed in water?

(c) The salt (NaCl) has dissolved in water. How do you know on the atomic level?

(d) What was the difference between the salt and sugar in water on the molecular level?

3. (a) Does the salt (NaCl) conduct electricity when dissolved in water?

(b) Does the sugar ($C_{12}H_{22}O_{12}$) conduct electricity when dissolved in water?

(c) Why is there a difference between the conductivity of salt and sugar?

Appendix S

General Chemistry Assessment Exam

1) Compared to the charge and mass of a proton, an electron has ______.

A) the same charge and a smaller mass
B) the same charge and the same mass
C) an opposite charge and a smaller mass
D) an opposite charge and the same mass

2) When electrons in an atom in an excited state fall to lower energy levels, energy is ______.

A) only absorbed
B) only released
C) neither released nor absorbed
D) both released nor absorbed

3) Which symbols represent atoms that are isotopes?

A) C-14 and N-14
B) O-16 and O-18
C) I-131 and I-131
D) Rn-222 and Ra-222

4) Which atom contains exactly 15 protons?

A) P-32
B) S-32
C) O-15
D) N-15

5) An ion with 5 protons, 6 neutrons, and a charge of 3+ has an atomic number of _____.

A) 5
B) 6
C) 8
D) 11

6) What is the mass number of an atom which contains 28 protons, 28 electrons, and 34 neutrons?

A) 28
B) 56
C) 62
D) 90

7) Which three groups of the Periodic Table contain the most elements classified as metalloids (semimetals)?

A) 1, 2 and 13
B) 3, 13 and 14
C) 14, 15 and 16
D) 16, 17 and 18

8) When a metal atom combines with a nonmetal atom, the nonmetal atom will ______.

A) lose electrons and decrease in size
B) lose electrons and increase in size
C) gain electrons and decrease in size
D) gain electrons and increase in size

9) Atoms of elements in a group on the Periodic Table have similar chemical properties. This similarity is most closely related to the atoms' _________.

A) number of principal energy levels
B) number of valence electrons
C) atomic numbers
D) atomic masses

10) As atoms of elements in Group 16 are considered in order from top to bottom, the electronegativity of each successive element _________.

A) decreases
B) increases
C) remains the same

11) Given the unbalanced equation: $Al + O_2 \rightarrow Al_2O_3$, when this equation is completely balanced using the smallest whole numbers, what is the sum of the coefficients?

A) 9
B) 7
C) 5
D) 4

12) What is the empirical formula of the compound whose molecular formula is P_4O_{10}?

A) PO
B) PO_2
C) P_2O_5
D) P_8O_{20}

13) What is the total number of atoms represented in the formula $Cu_2SO_4 \bullet 5\ H_2O$?

A) 8
B) 13
C) 21
D) 27

14) What is the molar mass of K_2CO_3 ?

A) 138 g
B) 106 g
C) 99 g
D) 67 g

15) 5.21 cm is the same distance as _________.

A) 0.0521 m
B) 52.1 dm
C) 5.21 mm
D) 0.00521 km
E) 5210 m

16) A value of $25°^{C}$ is a measurement of _________.

A) distance
B) volume
C) temperature
D) mass
E) density

17) The measurement of 0.0000043 m, expressed correctly using scientific notation is _________.

A) 4.3×10^{-7} m
B) 4.3×10^{-6} m
C) 4.3×10^{6} m
D) 0.43×10^{-5} m
E) 4.3

18) Which of the following measurements has three significant figures?

A) 0.005 m
B) 510 m
C) 0.510 m
D) 0.051 m
E) 5100 m

19) What is the density of a substance with a mass of 45.00 g and a volume of 26.4 mL?

A) 1.70 g/mL
B) 1.7 g/mL
C) 0.59 g/mL
D) 0.587 g/mL
E) 45.0 g/mL

20) Which of the following is an element?

A) tin
B) water
C) salt
D) sugar
E) iced tea

21) If the temperature is -55$^{\circ F}$, what is the corresponding temperature on the Kelvin scale?

A) 225 K
B) 218 K
C) 55 K
D) 273 K
E) 328 K

22) What elements are in hydroxyapatite, $Ca_5(PO_4)_3OH$, a major compound in human bones and teeth?

A) carbon, potassium, oxygen, and hydrogen
B) carbon, phosphorus, oxygen, and hydrogen
C) carbon, phosphorus, oxygen, and helium
D) calcium, phosphorus, oxygen, and helium
E) carbon, potassium, oxygen, and helium

23) Which of the following is a nonmetal?

A) nitrogen
B) sodium
C) iron
D) silver
E) calcium

24) The atomic number of an atom is equal to the number of ____________.

A) nuclei
B) neutrons
C) neutrons plus protons
D) electrons plus protons
E) protons

25) What is the mass number of an atom of potassium that has 20 neutrons?

A) 15
B) 19
C) 35
D) 39
E) 59

26) The elements sodium, magnesium, and silicon ____________.

A) are isotopes of each other
B) are in the same period of elements
C) have the same number of neutrons
D) are in the same group
E) have the same mass number

27) The maximum number of electrons that may occupy the third electron energy level is __________.

A) 2
B) 8
C) 10
D) 18
E) 32

28) What is the symbol of the element in Group IVA (14) and Period 2?

A) Be
B) Mg
C) Ca
D) C
E) Si

29) Valence electrons are electrons located __________.

A) in the outermost energy level of an atom
B) in the nucleus of an atom
C) in the innermost energy level of an atom
D) throughout the atom
E) in the first shells of an atom

30) In a molecule with covalent bonding, __________.

A) oppositely charged ions are held together by strong electrical attractions
B) atoms of metals form bonds to atoms of nonmetals
C) atoms of different metals form bonds
D) atoms are held together by sharing electrons
E) atoms of noble gases are held together by attractions between oppositely charged ions

31) The correct name of the compound NCl_3 is __________.

A) nitrogen chloride
B) trinitrogen chloride
C) nitrogen (III) chloride
D) nickel chloride
E) nitrogen trichloride

32) The name of $Al_2(SO_4)_3$ is __________.

A) aluminum (III) sulfate
B) dialuminum trisulfate
C) dialuminum sulfate
D) dialuminum trisulfide
E) aluminum sulfate

33) Which of the following compounds contains a polar covalent bond?

A) NaF
B) HCl
C) Br_2
D) MgO
E) O_2

34) Ionic bonding is expected in which of these compounds?

A) Cl_2
B) KF
C) OF_2
D) HF

35) The shape of the ammonia molecule (NH_3) is __________.

A) linear
B) square
C) trigonal pyramidal
D) hexagonal
E) octagonal

36) Which of the following gives the balanced equation for the reaction:

$$K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + KNO_3$$

A) $KPO_4 + CaNO_3 + KNO_3$
B) $K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + 3\ KNO_3$
C) $2\ K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + 6\ KNO_3$
D) $2\ K_3PO_4 + 3\ Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + 6\ KNO_3$
E) $K_3PO_4 + Ca(NO_3)_2 \rightarrow Ca_3(PO_4)_2 + KNO_3$

37) A mixture is prepared by dissolving 2 g of KCl in 100 g of H_2O. In this mixture, H_2O is the ________.

A) solute
B) solvent
C) solution
D) solid
E) ionic compound

38) When KCl is dissolved in water ________.

A) the Cl^- ions are attracted to the dissolved K^+ ions
B) the Cl^- ions are attracted to the partially negative oxygen atoms of the water molecule
C) the K^+ ions are attracted to the Cl^- ions on the KCl crystal
D) the K^+ ions are attracted to the partially negative oxygen atoms of the water molecule
E) the K^+ ions are attracted to the partially positive hydrogen atoms of the water molecule

39) In water, a substance that ionizes completely in solution is called a ________.

A) weak electrolyte
B) nonelectrolyte
C) semiconductor
D) nonconductor
E) strong electrolyte

40) When some of the sugar added to iced tea remains undissolved at the bottom of the glass, the solution is ________.

A) dilute
B) polar
C) nonpolar
D) saturated
E) unsaturated

Appendix T

Pre-Test Assessment

1) Which one of the following substances will float in gasoline, which has a density of 0.74 g/mL? The density of each substance is shown in parentheses.
A) table salt (D = 2.16 g/mL)
B) balsa wood (D = 0.16 g/mL)
C) sugar (D = 1.59 g/mL)
D) aluminum (D = 2.70 g/mL)
E) mercury (D = 13.6 g/mL)

2) What is the mass of 53.0 mL of ethanol, which has a density of 0.79 g/mL?
A) 67.1 g
B) 41.9 g
C) 42.0 g
D) 67.0 g
E) 53.0 g

3) Which of the following solutions is NOT acidic?
A) vinegar, pH 2.8
B) shampoo, pH 5.7
C) honey, pH 3.9
D) seawater, pH 8.5

4) Identify the conjugate base in the following equation.

$$HCl(aq) + Na_2CO_3(aq) \longrightarrow Na^+(aq) + Cl^-(aq) + HCO_3^-(aq)$$

A) Na^+
B) HCO_3^-
C) Cl^-
D) HCl

5) Isomers are molecules that share the same formula and have ________.

A) a different shape to the molecule
B) the same arrangement of atoms within the molecule
C) a different arrangement of atoms within the molecule
D) identical boiling points
E) the same shape in each molecule

6) In the three-dimensional structure of methane, CH_4, the hydrogen atoms attached to a carbon atom are aligned ________.

A) in a straight line
B) at the corners of a square
C) at the corners of a tetrahedron
D) at the corners of a rectangle
E) at the corners of a cube

7) In a solution, the solvent ________.

A) is a liquid.
B) can be a liquid or gas.
C) can be a solid, liquid, or gas.
D) is never a solid.
E) is the substance present in the smallest concentration.

8) Vinegar is a solution that contains approximately 4 g of acetic acid in 100 mL of water. Identify the solute and solvent in this solution of vinegar.

A) Vinegar is the solute; water is the solvent.
B) Water is the solute; vinegar is the solvent.
C) Acetic acid is the solute; water is the solvent.
D) Water is the solute; vinegar is the solvent.

9) A liquid has a volume of 34.6 mL and a mass of 46.0 g. What is the density of the liquid?
A) 1.00 g/mL
B) 1.33 g/mL
C) 0.752 g/mL
D) 1330 g/mL
E) 0.663 g/mL

10) The ratio of the mass of a substance to its volume is its ________.
A) specific gravity
B) density
C) buoyancy
D) weight
E) conversion factor

11) Which of the following can be used to measure pH of solutions?

A) A Buffer system
B) Universal Indicator Paper
C) Acetic acid solution
D) pH cannot be measured

12) The pH values of acids will always be ____________.

A) Exactly 7.0
B) Greater than 7.0
C) Less than 7.0
D) Neutralized

13) A hydrocarbon contains only the elements ________.

A) hydrogen and oxygen
B) carbon and oxygen
C) carbon and hydrogen
D) carbon, hydrogen, and oxygen
E) carbon, hydrogen, and nitrogen

14) Carbon atoms always have how many covalent bonds?

A) one
B) two
C) three
D) four
E) five

15) Oil does not dissolve in water because ________.
A) oil is polar
B) oil is nonpolar
C) water is nonpolar
D) water is saturated
E) oil is hydrated

16) Water is a polar solvent and hexane (C_6H_{14}) is a nonpolar solvent. Which of the following correctly describes the solubility of the solute in the given solvent?

A) mineral oil, soluble in water
B) $CaCl_2$, soluble in hexane
C) $NaHCO_3$, soluble in water
D) CCl_4, soluble in water
E) octane, soluble in water

17) A nugget of gold with a mass of 521 g is added to 50.0 mL of water. The water level rises to a volume of 77.0 mL. What is the density of the gold?
A) 10.4 g/mL
B) 6.77 g/mL
C) 1.00 g/mL
D) 0.0518 g/mL
E) 19.3 g/mL

18) In order to find out the volume of an irregular object, what method is used?
A) Triple Beam Balance
B) Volume Manipulation
C) Multiplication
D) Volume Displacement

19) The pH values of strong bases will always be ________ weak bases.
A) Greater than
B) Less than
C) The same as
D) Identical to

20) According to the Arrhenius concept, if HNO_3 were dissolved in water, it would act as ________.
A) a base
B) an acid
C) a source of hydroxide ions
D) a source of H^- ions
E) a proton acceptor

21) The simplest cycloalkane has ________.
A) one carbon atom
B) two carbon atoms
C) three carbon atoms
D) four carbon atoms
E) five carbon atoms

22) Compounds that have the same molecular formula but different arrangements of atoms are called ________.
A) isomers
B) isotopes
C) indicators
D) isozymes
E) isometrics

23) If solid NaCl (inorganic) was placed in a methanol (organic) solution, the NaCl would ________.

A) dissolve completely
B) dissolve slightly
C) not dissolve at all

24) Organic solutes are soluble in ________ solvents.

A) inorganic
B) organic
C) ionic
D) nonpolar
E) polar

25) Density is an example of a(n) ___________ property.

A) intrinsic
B) extrinsic
C) nontrinsic
D) exact
E) inexact

26) Density is defined as ________________.

A) volume per weight of a substance
B) weight per volume of a substance
C) volume per mass of a substance
D) mass per volume of a substance

27) Which of the following statements correctly describes the hydronium-hydroxide balance in the given solution?

A) In acids, $[OH^-]$ is greater than $[H_3O^+]$.
B) In bases, $[OH^-] = [H_3O^+]$.
C) In neutral solutions, $[H_3O^+] = [H_2O]$.
D) In bases, $[OH^-]$ is greater than $[H_3O^+]$.
E) In bases, $[OH^-]$ is less than $[H_3O^+]$.

28) When an acid reacts with a metal like Al, the products are ________.

A) water and a base
B) water and a salt
C) water and carbon dioxide
D) a salt and carbon dioxide
E) a salt and hydrogen

29) Some alkenes have geometric (cis-trans) isomers because ________.

A) the carbon atoms in the double bond cannot rotate
B) each of the carbon atoms in the double bond has four different groups attached to it
C) one of the carbon atoms in the double bond has two identical groups attached to it
D) the carbon atoms in the double bond are free to rotate
E) all of the carbon atoms in the compound are rigid and cannot rotate

30) Compounds that have the same molecular formula but different arrangements of atoms are called ________.

A) isomers
B) isotopes
C) indicators
D) isozymes
E) isometrics

31) A substance that carries an electric current when dissolved in water is called a(n) ________.

A) weak acid
B) strong acid
C) weak base
D) strong base
E) electrolyte

32) A substance that produces only a small number of ions in solution is known as a ________ electrolyte.

A) strong
B) weak
C) semi
D) non

33) There are two pieces of copper. Piece A is twice the mass and volume of piece B. How can we compare the two densities?

A) The density of A will be double the value of B
B) The density of B will be double the value of A
C) The density of A will be half the value of B
D) The density of B will be half the value of A
E) The densities of A and B will be the same

34) The most precise way to measure out 9.0 mL of liquid would be to use which instrument?

A) 10 mL beaker
B) 50 mL beaker
C) 100 mL beaker
D) 10 mL graduated cylinder
E) 50 mL graduated cylinder

35) The neutralization reaction between $Al(OH)_3$ and HNO_3 produces the salt with the formula ________.

A) H_2O
B) $AlNO_3$
C) AlH_2
D) $Al(NO_3)_3$
E) NO_3OH

36) The function of a buffer is to ________.

A) change color at the end point of a titration
B) maintain the pH of a solution
C) be a strong base
D) maintain a neutral pH
E) act as a strong acid

37) Which of the following substances has the same molecular and structural formulae, but different spatial arrangements?

A) structural positional isomers
B) optical isomers
C) functional isomers
D) cis-trans isomers
E) isotopes

38) Which of the following substances has the same molecular, but different chemical properties and behaviors?

A) structural positional isomers
B) optical isomers
C) functional isomers
D) cis-trans isomers
E) isotopes

39) When NH4Cl (inorganic) is added to water (inorganic), the salt will be ________.

A) soluble
B) insoluble
C) independent
D) a non electrolyte

40) Red litmus paper will turn blue in the presence of _________.

A) an acid
B) a base
C) NaCl (a salt)
D) any electrolyte
E) any nonelectrolyte